Modern-Life SCIENCE



Carleton · Williams

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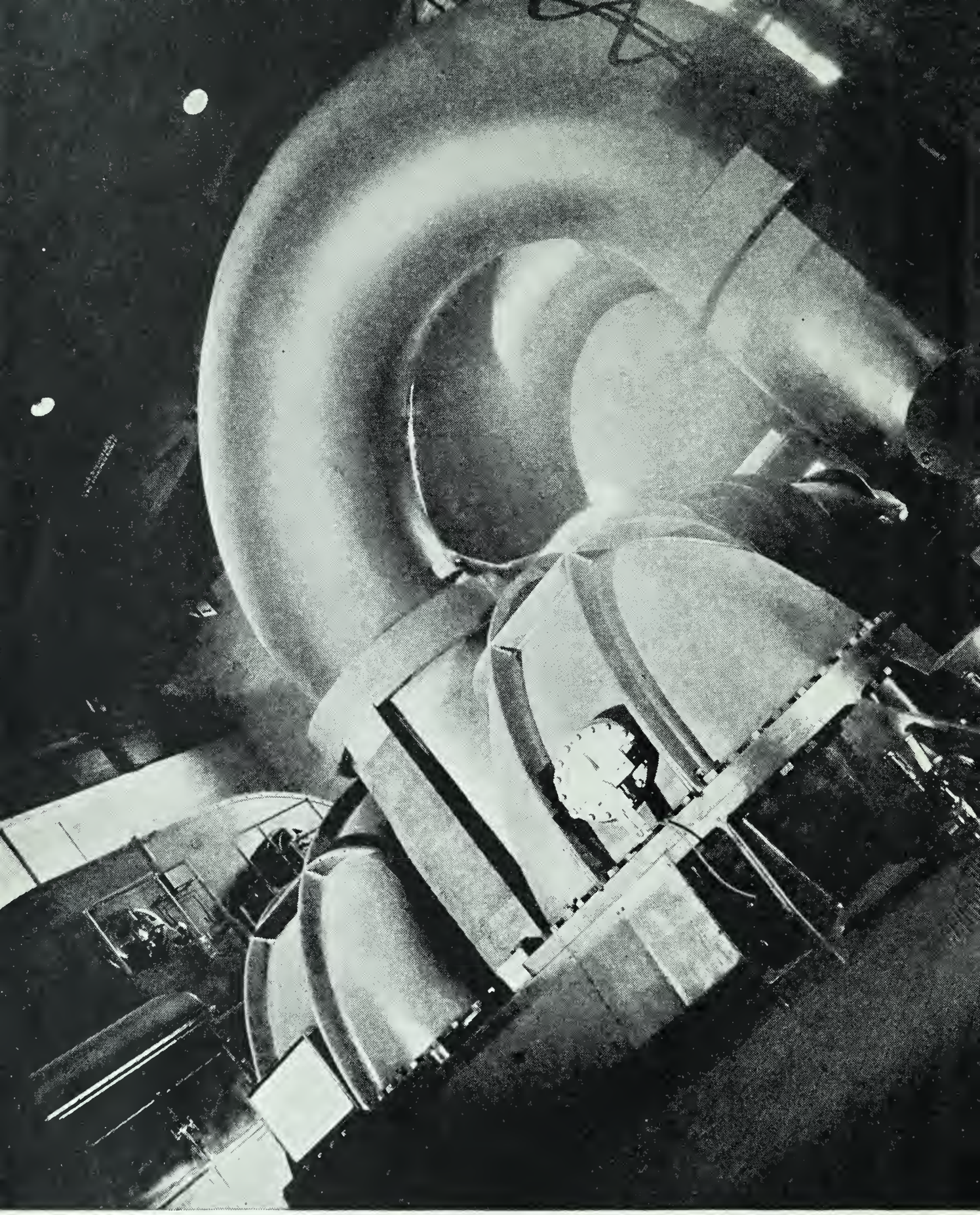


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MODERN-LIFE SCIENCE



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Chicago Philadelphia New York

MODERN-LIFE SCIENCE

ROBERT H. CARLETON
Summit High School
Summit, New Jersey

HARRY H. WILLIAMS
Horace Mann School for Boys
New York City

WHITE-ON-BLACK DRAWINGS BY T. R. MILLER

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A LETTER FROM THE AUTHORS TO YOU

Fellow Science Instructors:

Recent years have witnessed accelerated efforts by forethinkers in education, by policy-making committees, by progressive teachers, and by textbook writers to broaden the scope of science instruction so as to make it more functional—and to do so for the sake of the general education of all students, regardless of whether they go to college. As far back as 1932, Professor Charles J. Pieper urged a reorganization of the secondary-school science program around "desirable specific adjustments in relation to the aspects of the environment which are most significant in everyday life."

A systematic effort in this direction seems logically to involve at least three major steps: (1) setting up objectives and redefining them in terms of desirable changes in pupil behavior; (2) selecting materials of instruction and planning activities designed to effect these changes; (3) devising new instruments of evaluation to determine the effectivenss of these materials and activities. This emphasis upon the statement of objectives in terms of individual growth and development through more and more adequate adjustment to the world about him, rather than in terms of knowledge or subject matter in a more limited sense, has led to a more realistic consideration of such objectives as improving the ability to recognize and define problems, to formulate and test hypotheses, to observe adequately and objectively, to interpret data, to apply facts and principles to new situations, and to develop the specific scientific attitudes essential to clear and unbiased thinking. These, in turn, have significance as objectives only as they contribute to the creation of a total individual whose experiences in science make him more effective in his personal living and socioeconomic relationships by developing understandings that are real to him and concern major aspects of his environment.

It becomes obvious that such noteworthy objectives will have validity and meaning only to the extent that the teacher is successful in planning experiences and activities for their attainment. It seems safe to say that students in the classroom have not learned very much about problem-solving techniques, chiefly because teachers have assumed that by teaching them the subject matter, students will develop their problem-solving abilities as a natural and necessary by-product. As long as we adhere to and

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practice this belief, improvement of problem-solving abilities and the development of scientific attitudes will come out a poor second. We must set out consciously and actively to teach these things. The importance of these goals of instruction is stated in the following quotation from the writings of John Dewey:

"The future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind; . . . the problem of problems in our education is therefore to discover how to mature and make effective this scientific habit . . . Scientific thinking is the only method of thinking that has proved fruitful in any subject."

Turning to more specific knowledges as a goal of instruction, we should realize the necessity of developing understandings of important concepts, principles, and generalizations. Such understandings should be developed from experiences and the study of scientific facts, but they are not the necessary concomitants of the study of facts alone. Memorization of the statement of a principle made by a teacher or textbook does not constitute learning or understanding of such a principle. These things must be developed through activities, experiences, and pupil participation. Furthermore, if scientific principles are to become functional, they must be used in a number of situations other than the ones in which they were developed.

The authors of this book have attempted to facilitate these tasks, not by popularizing or diluting a traditionally conceived and organized science program but by consistently organizing so-called subject matter in terms of its utility in aiding the pupil to solve more intelligently those problematical situations of human living which require us to make adjustments to the forces and materials of our environment. Our criterion has been this: To what extent can we open new horizons for the student by showing him how science can be of real service in aiding him to appreciate and understand more fully significant aspects of the world in which he moves and to which he must adjust? Such insights, because they reveal both the functioning of the scientific method and its tremendous significance to his own daily living, should function to leave with the student a more abiding interest in science and a truer appreciation of scientific, as opposed to nonscientific, modes of thinking and attitudes. To do this, it has been necessary to consider the probable science background and both the present and the future needs of the pupil. No subject matter has been included simply because it is traditionally found in science courses or because it could be presented in the classroom with a minimum of effort and planning.

By way of summary, let us review the several assumptions which underlie the philosophy of science for the sake of adjustment:

1. Our environment includes a number of forces and materials with which man is constantly interacting and which require him to make adjustments to them (that is, to do something about them).

2. These problems of human living may require adjustments of us individually or collectively; the adjustments may be intellectual or practical.

3. For the purpose of general education, "science" must be construed to consist of knowledges concerning the forces and materials of our environment, of scientific problem-solving techniques applicable to adjustment problems, and of scientific attitudes (including appreciations) regarding the problems of living.

4. To solve these problems of human adjustment in an intelligent and effective manner requires the use of conscious techniques of scientific problem-solving and the application of a broad knowledge of the field of science, both being governed by the accepted scientific attitudes.

5. The knowledges which contribute to an understanding of the significance to us of the forces and materials of our environment usually cut across man-made boundaries and come from several of the specialized fields of science. Seldom are they confined to a single one.

6. The real problems of adjustment arise from the felt needs and desires of daily human living. These needs and desires, therefore, are the purposes served by "science designed for better human adjustment."

Among the needs and desires which give real purpose and practical value to a physical science course developed on this basis are the following: to provide materials necessary to life (food, water, air, etc.); to maintain better health; to secure greater comfort, convenience, and safety; to develop wiser "consumership" and to increase economy; to engage in scientific leisure-time activities; to promote more effective conservation; to participate more fully in social and economic adjustment in a democracy; to understand "the science world-picture"; and to substitute action based on critical thinking for action based on intolerance, prejudices, traditions, superstitions, and misconceptions. These are the criteria by which to judge whether or not certain materials and activities go into the course. The materials and activities included in this physical science course, as presented in the textbook and workbook, have high potential value in helping us to make better adjustments along these lines so that we may live a more liberal, practical, and cultured life.

The following books are valuable sources for obtaining a fuller understanding of the problem and its solution:

National Society for the Study of Education, Thirty-first Yearbook, Part I. A Program for Teaching Science. Public School Publishing Company, Bloomington, Illinois, 1932.

Beauchamp, W. L., Instruction in Science. U. S. Office of Education Bulletin, 1932, Number 17, Monograph 22.

Downing, E. R., Introduction to the Teaching of Science. The University of Chicago Press, Chicago, 1934.

Editorial, "Science for Adjustment." Science Education, Volume 20, Number 3: 169, October, 1936.

"Report of the Committee of the N. A. R. S. T.," Science Education. Volume 23, Number 4: 179-187. April, 1939.

P. E. A., Science in General Education. D. Appleton-Century Company, New York, 1938.

Heiss, E. D., Obourn, E. S., and Hoffman, C. W., Modern Methods and Materials for Teaching Science. The Macmillan Company, New York, 1940.

Hawkes, H. E., Lindquist, and Mann, C. R., The Construction and Use of Achievement Examinations. Houghton Mifflin Company, Boston, 1936.

It is a pleasure to acknowledge the assistance of those who contributed so generously in one way or another to the preparation of this book. We wish to express our sincere appreciation to:

The American Gas Association Testing Laboratories for their careful checking of the sections on gaseous fuels and devices for their combustion.

The American Petroleum Institute for their careful checking of the sections dealing with liquid fuels.

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The General Motors Corporation for making available the large number of illustrations credited to them in Units Two and Six and for permitting us to adapt certain portions of their booklets, Electricity and Wheels and Metallurgy and Wheels, for use in these same two units.

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Numerous individuals, commercial firms, and other agencies for their generous cooperation in furnishing suitable illustrations. The particular indebtedness of the authors is acknowledged by the credit line in connection with each illustration.

The individuals or agencies who read critically practically all of the units not listed above but requested that specific individual acknowledgment of their services be withheld.

We would appreciate any comments or helpful criticisms which the users of this book—teachers or students—may care to offer.

Sincerely yours,

P. H. Carleton

Harry H. Williams

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CALLS AREA DRY DESERT

Philosophical Society Marks Centenary of Wilkes Trip of Exploration

Special to THE NEW YORK TIMES.

PHILADELPHIA, Feb. 23—The paradoxical view that glaciers in

VETS TO GIVE IRON LUNG TO HOSPITAL

CUBIC INCH OF STAR WEIGHS 9,000 TONS

American Tells Scientists Meeting in Paris of 'White Dwarfs' Recently Discovered

Copyright, 1939, by Science Service

PARIS, July 19.—A star so heavy that a mere cubic inch of its matter weighs nearly 9,000 tons was described to the Singer-Polignac Congress of Astrophysics here this

NEW ATOM SMASHING RAY

California Scientist Tells of Producing 19,000,000-Volt Beam

BERKELEY, Calif., June 16 (AP).—A high-power atom smashing ray which may bring science closer to the mastery of boundless energy was put into use today at the University of California.

Flood in Peru Takes Heavy Toll

Huaraz, Peru, Dec. 13.—(UP)—At least half of this city was destroyed today and many were killed

NEW MAGNETIC STORM UPSETS RADIO PHONES

Short-Wave Channels Abandoned When Ethereal Blasts Recur

Renewed manifestations of the magnetic storm that since last Sunday has been upsetting short-wave radio and creating havoc with international radio traffic happened

SAYS THE 'EVIL EYE' MADE HIM KILL WIFE

Philadelphian Declares He Feared 'Murder Ring' Spell

YOU AND PHYSICAL SCIENCE

New Instrument Records Sky Temperature; System of Mirrors Aids Weather Forecasts

Last Concrete in Grand Coulee Dam

Grand Coulee, Wash., Dec. 13.—(AP)—The last bucket of concrete has been tipped into Grand Coulee dam, completing the physical features of the massive barrier which raises its 550-foot-high bulk against the waters of the Columbia river.

The bureau of reclamation, mak-

Soap May Lose Whiteness Soon; Oil Supply Low

VAST POWER SOURCE IN ATOMIC ENERGY OPENED BY SCIENCE

Relative of Uranium Found to Yield Force 5 Million Times as Potent as Coal

GERMANY IS SEEKING IT

Scientists Ordered to Devote All Time to Research—Tests Made at Columbia

Sun in Milky Way Bursts, Showers Crust Into Space

ERFURT, Germany, Jan. 20—Astronomical observatories at Hamburg and Sonneberg today reported a "catastrophe of gigantic magnitude" in the firmament. It was an explosion of a sun in the Milky Way.

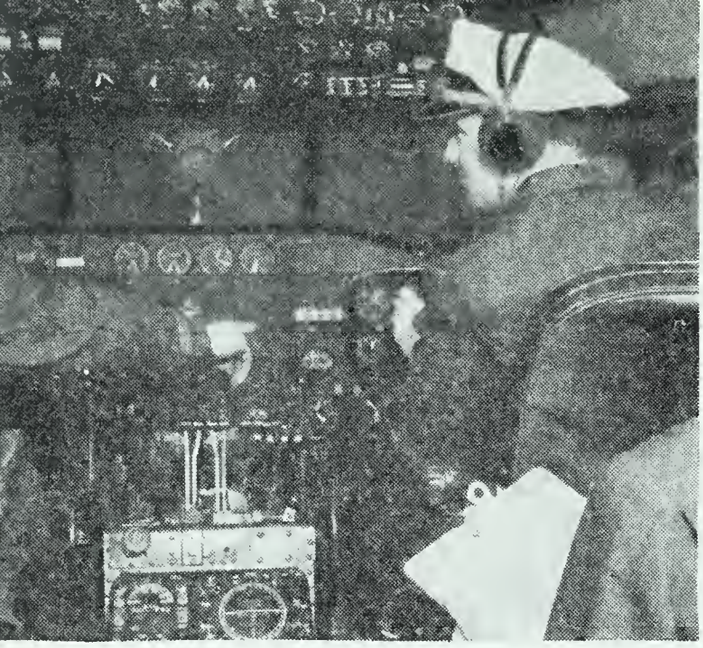
In consequence of the sudden release of energy the crust of the exploding star was shot into space in all directions and at the tremendous speed of several million kilometers an hour.

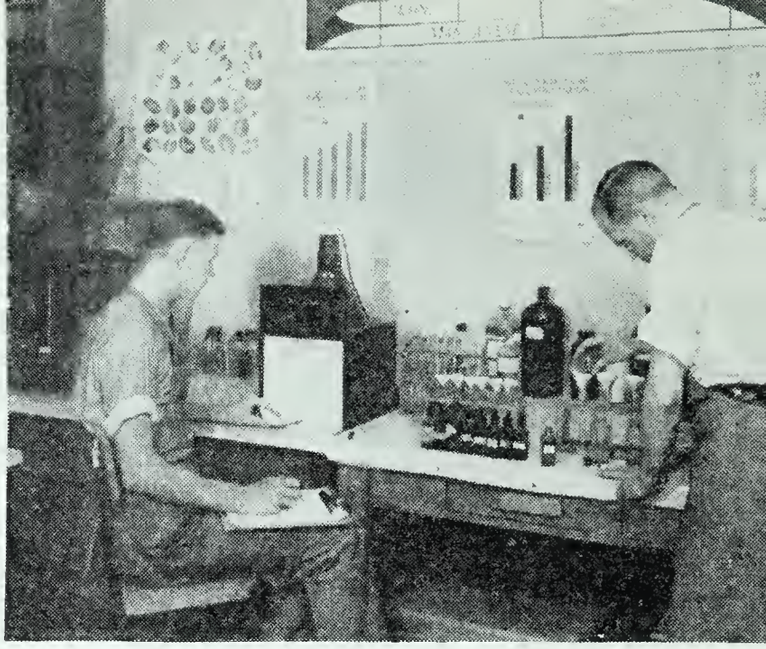
Radium Excelled By New Device

'Electron Maelstrom'

Schenectady, N. Y., Dec. 16.—(UP)—Development of a 20,000,000 volt "electron maelstrom" capable of producing an electronic stream far more penetrating than that of radium was announced here today by the General Electric research laboratory.

Through the new device, based





Photos courtesy T.W.A. (left); American Agricultural Chemical Company (right)

Left: The officers and navigators of modern stratoliners must have a thorough knowledge of science for correct interpretation of the data registered by the instruments on the panel board.
Right: These chemists analyze samples of soil to find what elements are present and which are lacking. They tell farmers how much nitrogen, phosphorus, potassium, or other elements will make their soil yield better crops.

The Authors Introduce

YOU AND PHYSICAL SCIENCE

So you're going to study physical science! Splendid! This course should be one of the most interesting and worth-while courses you can take. Everyone realizes that we live in a world characterized by the wonderful achievements of science and their applications, and everyone ought to realize that there are two big reasons why we should study science as a part of our formal education.

First—a knowledge of science is essential to a well-rounded, general education. People like to be informed, to understand the "how" and the "why" of various happenings, and to know the answers to such questions as: What makes a fire burn? Why do the stars twinkle? How do we know that much of North America was once covered with ice? How does the automobile engine work? How are sound motion pictures produced and shown? What is the cause of thunder, lightning, or the rainbow? How does a radio work? How is electricity generated? What is fluorescent lighting? What are alloys and plastics made of? Without a knowledge of the answers to these and a thousand and one similar questions, a person finds it difficult to read with understanding many articles in the magazines and daily papers. The page of newspaper clippings at

the beginning of each unit in this book gives some indication of the extent of "science in the news." An individual who is unfamiliar with science frequently finds his lack of knowledge a social handicap, because he cannot participate in many ordinary conversations or even understand what others are talking about.

Second—a knowledge of science is of practical use to everyone. The doctor, the engineer, the science teacher, the factory superintendent, the chemist, the pharmacist, the architect, and many other types of workers must have an extensive knowledge and command of many fields of science. But what about the bank teller, the office worker, the stenographer, the homemaker, the minister, the farmer, the English teacher, and the man who runs the grocery store, the filling station, the candy shop, or the cigar stand? They, too, need a working knowledge of science, but a different kind of science than is needed by persons in the first group. The former are *producers* in science—their vocations are more or less branches of science—while the latter are *consumers* in science. As consumers, we all have need for the kind of science that helps us in our daily living—that is, an understanding and working knowledge of important science ideas, laws, and principles. That is the kind of science you will find stressed in this book—the science which will help *you* to do things in better ways so that you may live more healthfully, more comfortably, and more safely, with greater efficiency, economy, convenience, and enjoyment. Science becomes useful when it helps us to solve the problems of daily living, such as: Shall I purchase a gas or an electric range for my kitchen? Shall I insulate my house? How can I insure the purity of my drinking-water? Shall I vote "yes" on the proposal to build a municipal electric plant? How can I remove ink spots from a tablecloth? Is a noise abatement campaign in my town justifiable? How can I decrease the amount of fuel needed to heat my home in winter? Is my home adequately lighted? How can I extinguish a fire in the broiler? If you can add another dozen, or a hundred, similar questions to this list, you will have set up for yourself an excellent set of objectives to keep in mind throughout the course.

Remember, too, that the study of physical science provides an excellent opportunity for you to explore more carefully your interests and aptitudes in science. Perhaps you will discover a thread of interest that will lead to a definite vocation. At least, you might discover interests which may develop into absorbing hobbies, or spare-time activities, that will be a life-long source of pleasure.



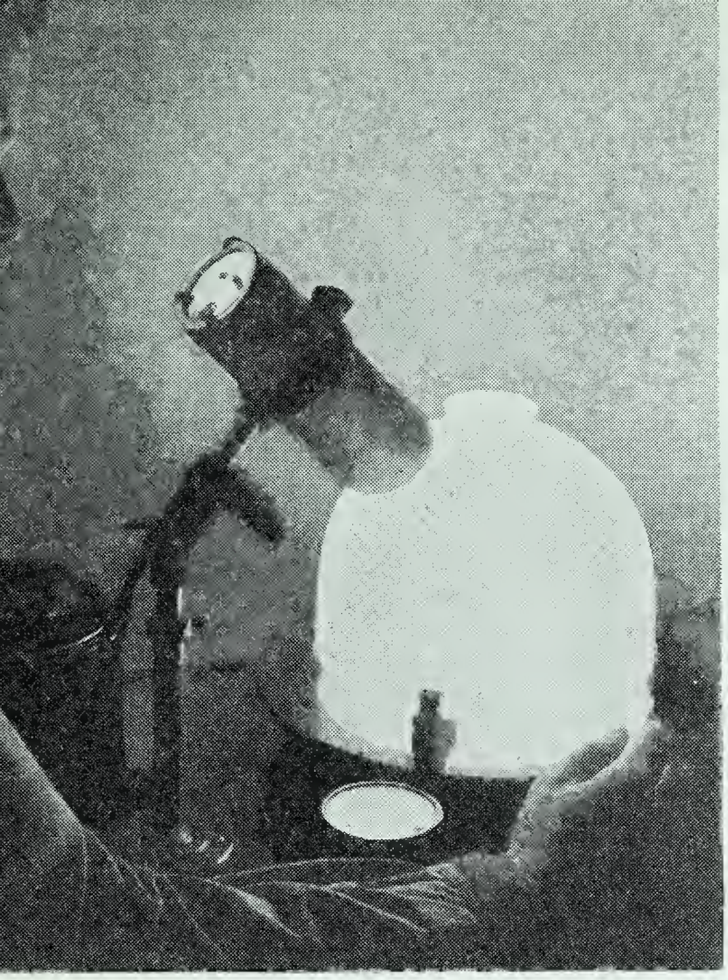


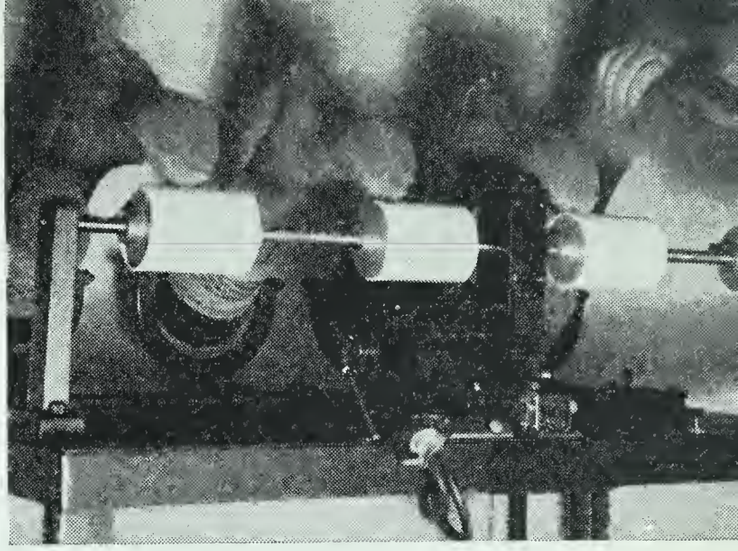
Photography is a science hobby which affords a great deal of pleasure and satisfaction. Start with the simple outfit pictured at the left; later you may work up to the de luxe equipment shown at the right.

Knowledge of science is not enough, however—you must have a desire and an intention to act according to what you have learned. Once you have learned about natural laws, you should be willing to conform to them or to pay the price of disobeying them. The man who knows that, as he doubles the speed of his car, the tendency to overturn at a curve is multiplied by four is simply a fool if he "takes" a sharp curve at sixty miles an hour when he is riding alone on a deserted highway. If there are passengers in the car or there is other traffic on the road, he is a menace to society. As you study this course, be alert to your environment; try to recognize the problems which your science may help you solve, and then try to solve them by observing, experimenting, and applying what you have learned.

What is the greatest contribution of science to humanity? Do you think it is radio? The germ theory of disease? Radium? The discovery of electromagnetism? The harnessing of the power of steam or gasoline? No, it is none of these. It is *the scientific method and attitude.* John Dewey, foremost philosopher and educator of our time, has described the scientific attitude as "the most significant thing that has ever happened to the human race" and claims that "the future of our civilization depends upon the widening spread and deepening hold of the scientific habit of mind. . . . Scientific thinking is the only method of thinking that has proved fruitful in any subject."

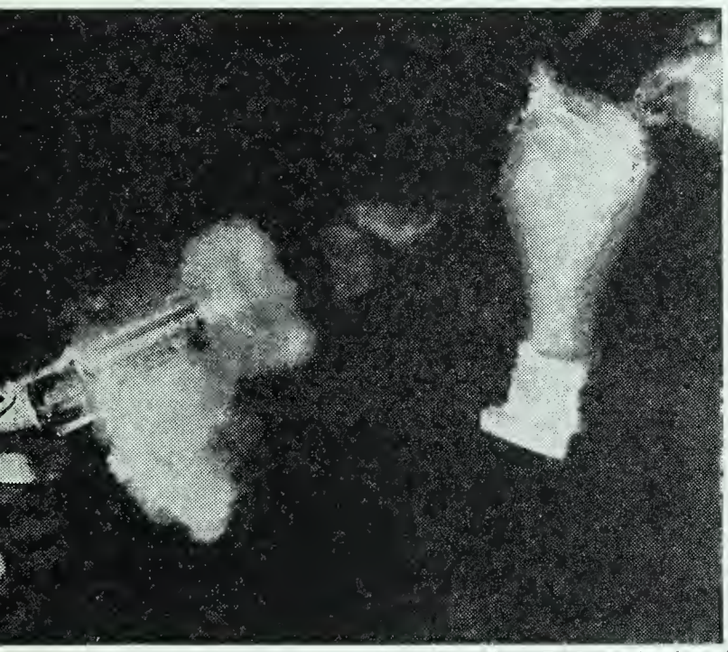
Dr. A. J. Carlson, eminent University of Chicago physiologist, has this to say about science: "The greatest thing in science is the scientific method, controlled and rechecked observations and experiments, objectively recorded with absolute honesty and with-





Above: This machine measures the wear-resistance of the toes and heels of stockings. How can the results obtained from such tests help the consumer?

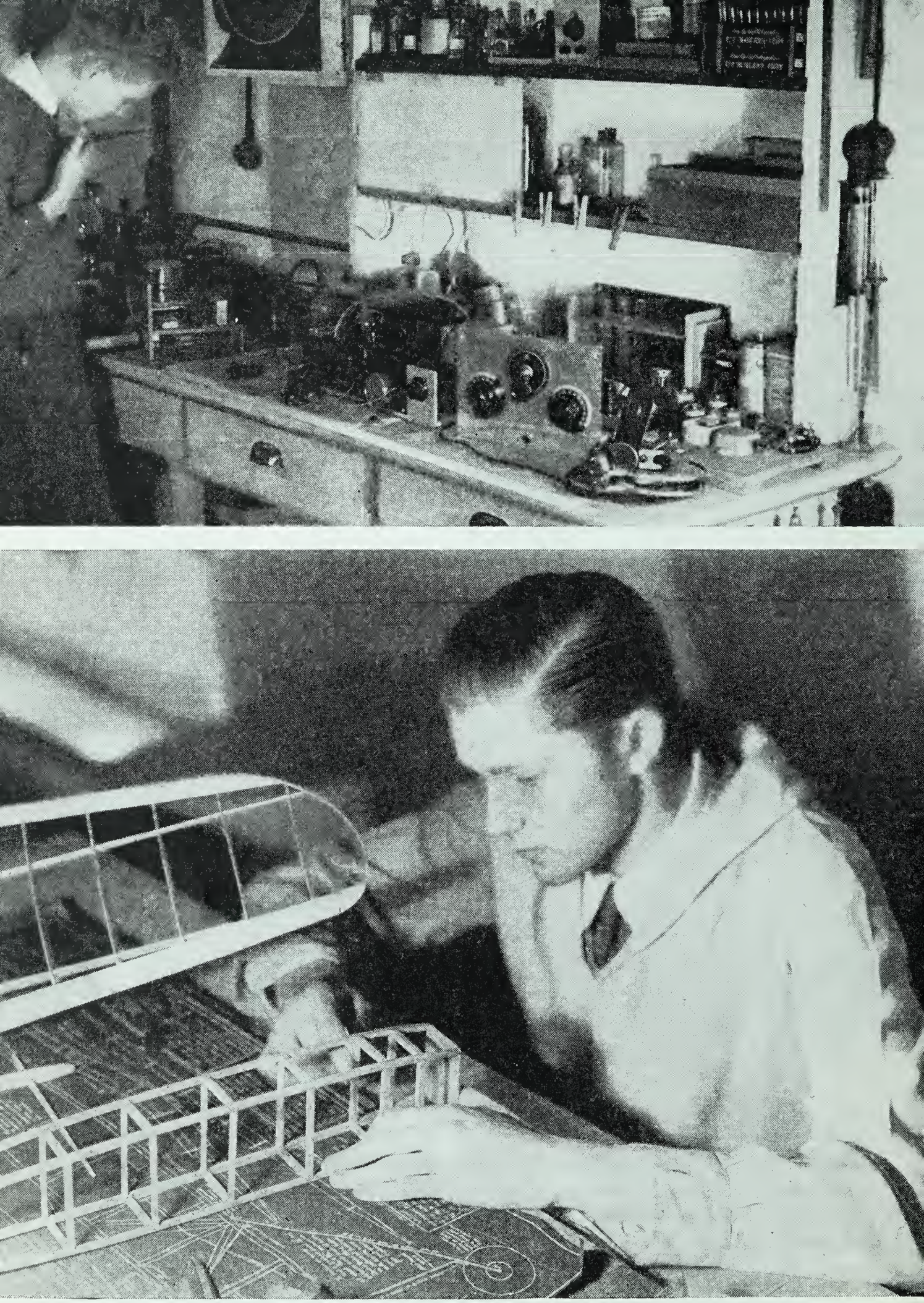
Left: The man is using a foot-candle meter to determine whether a diffusing reflector prevents glare. Thus the "electric eye" helps to safeguard the priceless vision of the human eye.





Photos courtesy Electrical Testing Laboratories (top left); U. S. Bureau of Home Economics (top right); General Radio Company (bottom left and right)

The stroboscope makes it possible to view at intervals a rapidly moving object. It thus produces the optical effect of slowing down or stopping motion. A flash of light from the stroboscope recorded the scene at the left for the camera before the shattering light bulb had time to collapse. At the right we see the stroboscope aiding in the adjustment of the cutters of electric shavers.



Courtesy New York Museum of Science and Industry

Building model airplanes or radios is a fascinating hobby which affords opportunity for applying science principles.

out fear or favor. Science in this sense has as yet scarcely touched the common man, or his leaders."[1]

These statements drive home the idea that the great strides made in scientific research, discovery, and application have been largely due to the method of thinking used by scientists and to the attitudes which direct their thinking; furthermore, that scientific thinking is useful in solving nonscience problems and is a valu-

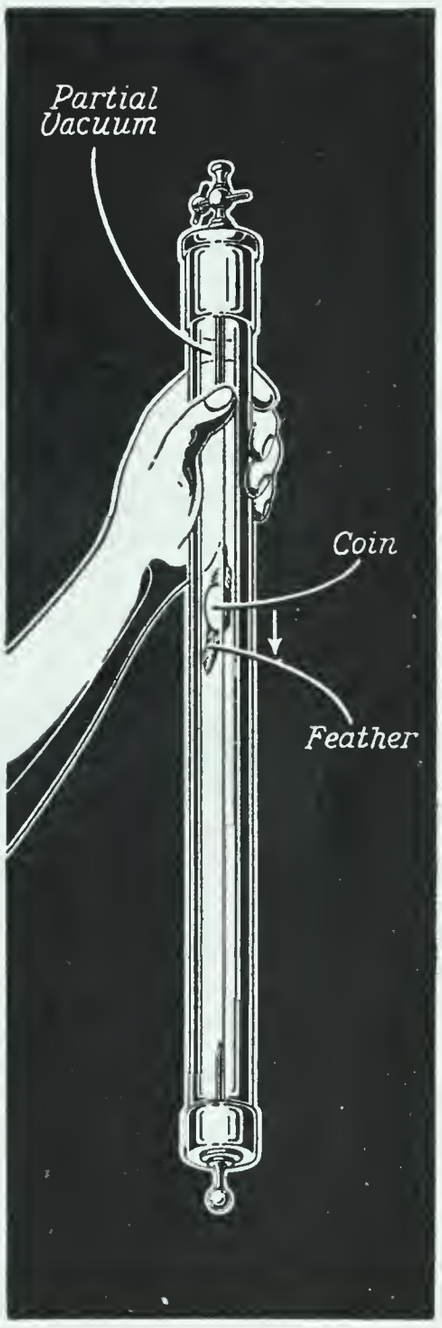


People do not always agree on their observations. How has science made observing more accurate?



Science Service

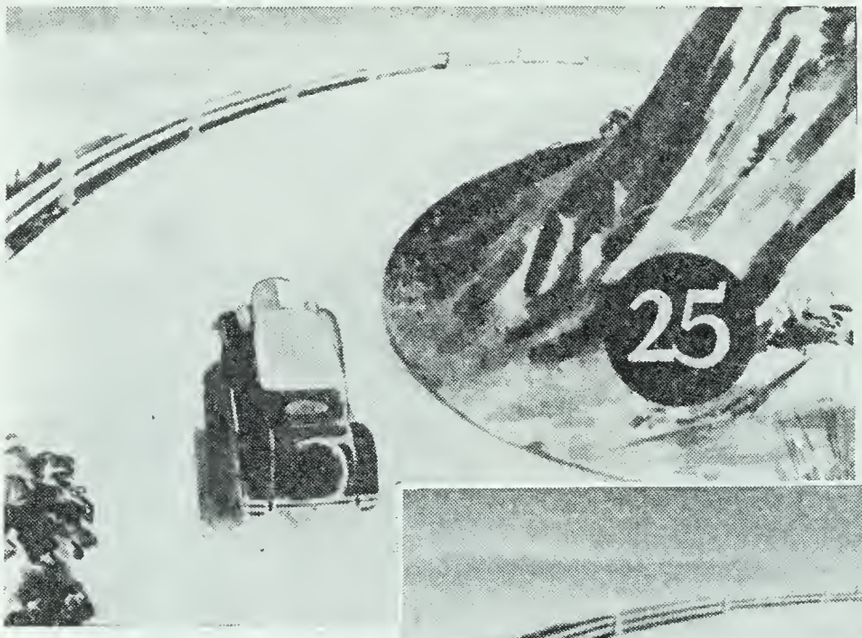
The ancients used divining rods in their search for metallic ores. This unfounded belief persists even today; some people use a forked stick in searching for underground water.



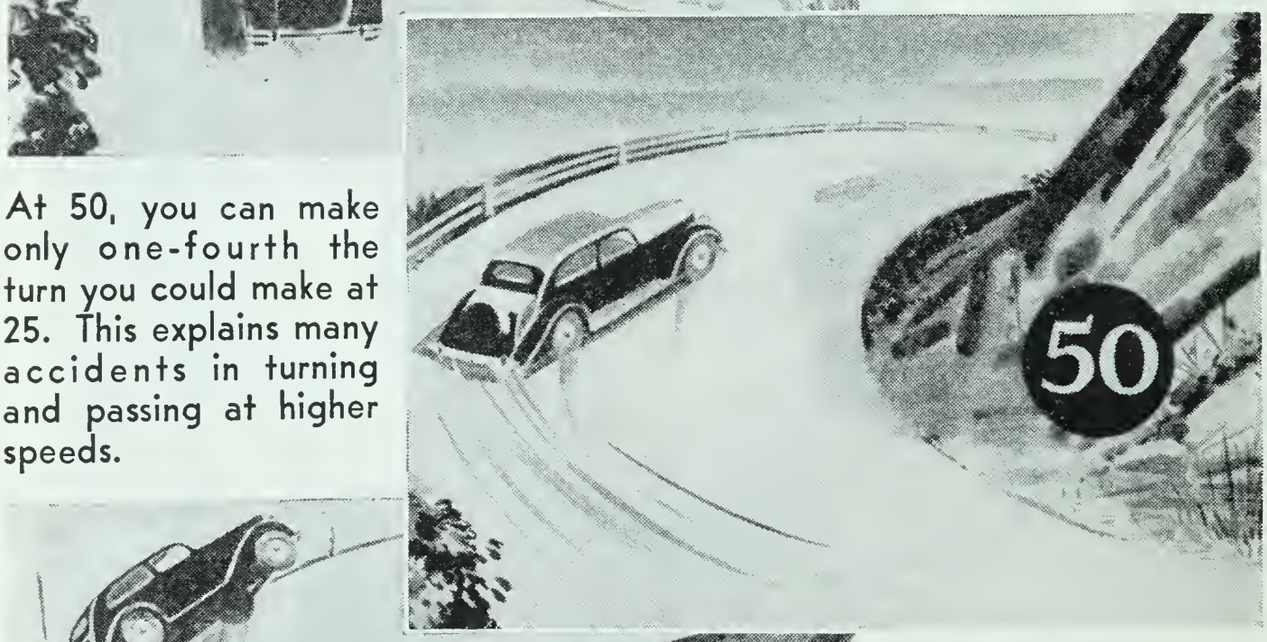
Objects of different weight fall at the same rate in a vacuum.

[1] "Science Versus Life," *Sigma Xi Quarterly*, Vol. 28, 1940.

The first law of motion is that a moving body tends to continue in uniform motion in a straight line. The energy of a moving body is in proportion to the square of the speed.



At 25 miles an hour, however, you can make a fairly sharp turn.



At 50, you can make only one-fourth the turn you could make at 25. This explains many accidents in turning and passing at higher speeds.



And at 75, your "turnability" has been cut to one-ninth that when you were going at 25. Try to turn more sharply than this law of nature allows, and over you go!

Courtesy Travelers Insurance Company

able habit for everyone to develop. Elliot R. Downing believes that "government of the people, by the people, for the people, is safe only when they can think clearly or at least recognize clear thinking."

Action based on critical thinking is gradually replacing action based on less reliable standards. Science has rooted out of our thinking many of the superstitions, traditions, and unfounded beliefs which characterized the thinking of only a few centuries ago. Primitive peoples believed, and still believe in unenlightened parts of the earth, that disease, pestilence, famine, earthquakes, storms, and floods are visitations of the wrath of gods, demons, and spirits. We are familiar with methods employed by such peoples to appease the gods.



Science Service

Which do you consider a more reliable weather forecaster—this groundhog or the weather scientist?

Ignorance and superstition have often blocked the path of progress. Early men, even though curious about the world of their day, were content to accept mystical explanations, to rely on traditions, or to turn to the religious authorities for their opinions. During the Golden Age of the ancient Greek civilization, about 350 B. C., efforts were made to collect, systematize, and catalog the world's knowledge. Conclusions and answers to questions were developed from meager observations and largely by "armchair philosophy"—that is, by argument, debate, and reasoning out to what seemed the logical conclusion. Because of insufficient data, erroneous observations, and other shortcomings, many conclusions were false or incomplete. Nevertheless, they were included in the great encyclopedia of human knowledge compiled by Aristotle. For nearly two thousand years, this book and a few others were accepted as the final authorities on nearly every question that arose. Of course, there were a few skeptics—there always are, fortunately.

Among the early pioneers in the scientific method, Galileo



Ewing Galloway

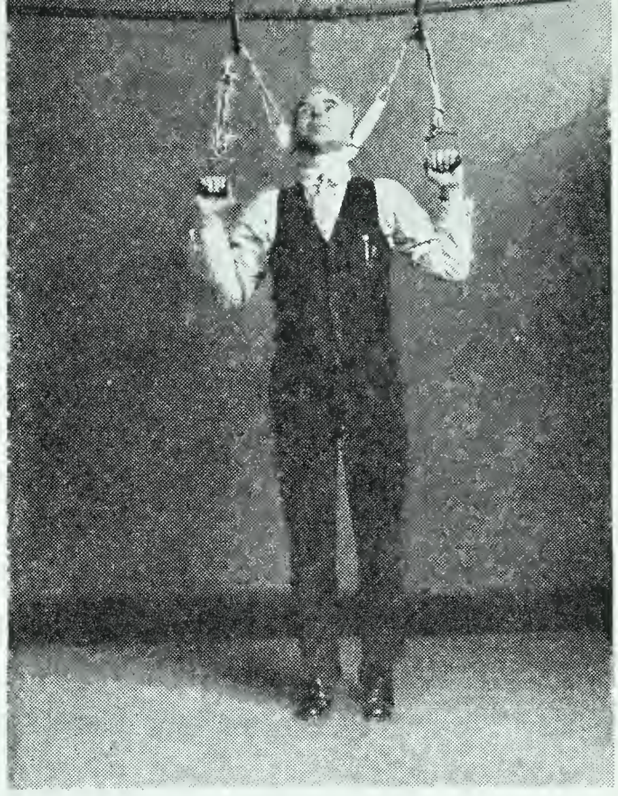
He sees all, knows all, tells all—but if he's right, he's just plain lucky.

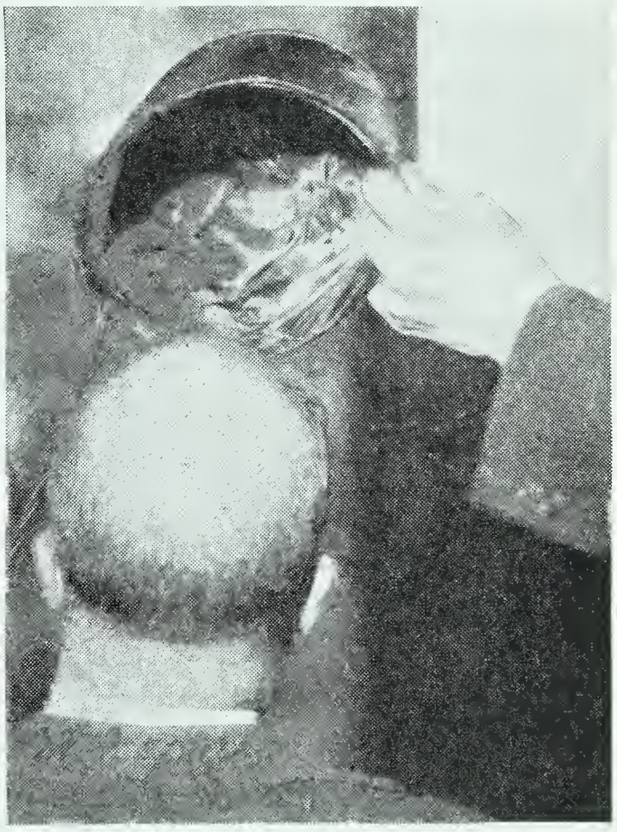
(1564-1642) was outstanding. He refused to accept the authority of the past and consistently sought to reach conclusions on the basis of experimentation. As an example, Aristotle had written that when objects of different weights are dropped, they fall to earth with speeds proportional to their weights. In other words, heavy objects fall faster than light ones. For about nineteen hundred years, this belief had gone unchallenged; but Galileo dared to question it. To get the answer to his question, he dropped objects of different weights simultaneously from the Leaning Tower of Pisa. So far as he and several learned witnesses were able to tell, the objects struck the earth simultaneously. The witnesses shook their heads; they weren't sure they should believe what they saw—for hadn't Aristotle written otherwise? But regardless of what they believed or what Aristotle had written, the truth had been determined; the practice of obtaining scientific information by experiment was established.

Although the habit of scientific thinking has made much headway, there is still room for great improvement. Superstitious beliefs have not yet been wiped from the face of the earth. Even in the United States there are people today who "test their faith" by allowing rattlesnakes to bite them. Some people still believe that the earth is flat. Science has definitely proved that weather is the result of the interaction of natural forces and materials—yet during a prolonged drought, newspaper items usually appear telling of communities or individuals who have engaged the services of "rain-makers" to bring down water from the clouds to a parched earth. Notice how many astrology magazines are displayed on the newsstands. Do you think people really take them seriously? Have you ever heard of a case in which the parents of a child ill of pneumonia, typhoid fever, diphtheria, or a similar

germ disease have refused medical aid and insisted on treating it by some more or less mystical belief—only to have the child die? Several occur each year; you can read about them in the daily papers. Speaking of newspapers, notice whether the one you read publishes each day's horoscope based on the stars and planets, or perhaps an advertisement stating that they will send it to you for a nominal sum. Sometimes you are supposed to send in a sample of your handwriting and a dime to receive a forecast of your future with advice as to the best course of action. You would be rich if you had only one-tenth of the money spent annually in the United States by people who consult fortunetellers, spiritualists, and similar prognosticators.

The number of people who consult fortunetellers of one type or another is small, however, when compared to the number of people who solve their problems, make decisions, or base their course of action on tradition and custom, hearsay, intolerance, prejudice, propaganda, and misinformation. This latter group includes nearly all of us, at least at one time or another. It is convenient to let others do our thinking for us, even though it may not always be to our own





Courtesy *Consumers' Guide;* U. S. Food and Drug Administration

Top: Mr. Consumer occasionally "gets it in the neck." This time it's a stretching device alleged to increase his height.

Bottom: An electric skullcap supposed to make hair grow might appeal to persons unable to recognize false advertising. Such fake devices are now prohibited by law.

best interests. It is easy to keep on doing things in a certain way just because they have always been so done. Which is a more scientific attitude to adopt: "What was good enough for father is good enough for me," or, "Let's judge the case on its own merits"?

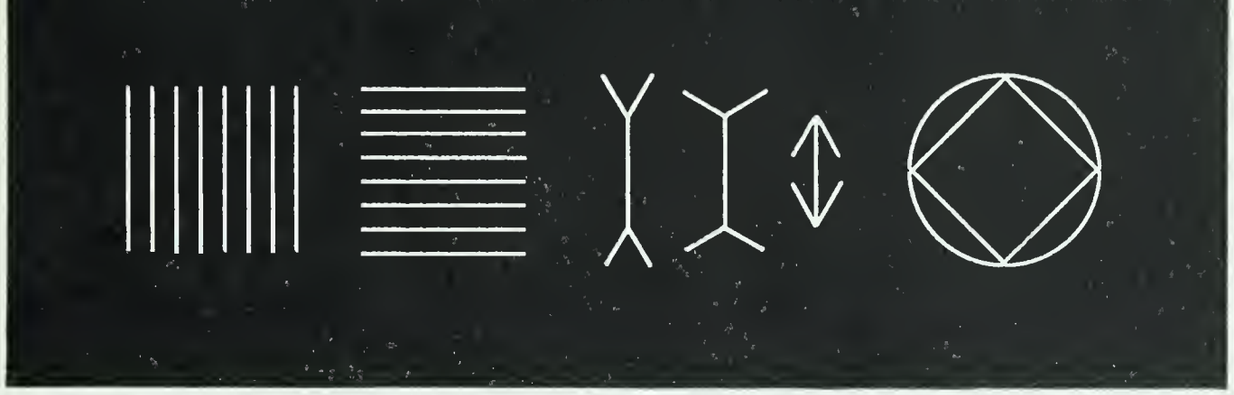
People in general are still very gullible; they are easily "taken in." A few years ago in a large midwest city, the Better Business Bureau was besieged by a dozen indignant citizens who told similar stories of being swindled by a man claiming to have a patent on a powder for use in making "medicated, fruit-flavored" doughnuts. Recently in New York City, the dishwasher in a restaurant told his employer he had invented a machine which would turn $5 bills into $10 bills. The employer bought the machine for three thousand dollars in cash, which he withdrew from a bank. The dishwasher, of course, vanished. Three days later, after the fraud had been discovered, the restaurant owner found the culprit in Central Park; he seized the man and called the police. Justice was administered, but the restaurant owner recovered only one thousand dollars.

The scientific method consists, ideally, of several definite steps or procedures. These steps may be summarized as follows:

1. Recognizing and defining a problem.
2. Setting forth hypotheses which, if true, would form satisfactory solutions of the problem.
3. Collecting data, using the hypotheses one after another as guides to observation, investigation, and experimentation.
4. Organizing and analyzing data so that it may be interpreted, inferences drawn, and conclusions reached.
5. Testing conclusions and applying them to the original problem and to new situations.

All thinking begins in a "forked road" situation—that is, in a situation where a perplexity is recognized, a difficulty is felt, or a question arises to which there seem to be several possible answers. In any event, the situation must be thought over and the difficulty clearly defined. The first step in solving a problem is to understand what the problem is. The other steps may not always follow in the same sequence, but they are nearly always involved in solving a problem by the method of science.

Hypotheses may be thought of as hunches as to what the solution to the problem might be. Although several promising hy-



How might optical illusions be useful? How do scientists eliminate them from observations when they might lead to erroneous conclusions?

potheses may come to mind, one usually seems most plausible because of past experience in similar situations or because of certain knowledge one may possess that relates to the situation. The most plausible hypothesis is used as a guide to the collection of more information relating to the problem.

Information may be obtained from books, from laboratory experiments, from observations of the environment, from recall of past experience, and from other sources. In collecting data, we should remember the limitations of the human senses. Look at the illustration. Are your senses always to be trusted? To aid and extend the senses and to increase accuracy in observations, numerous scientific instruments have been devised. Microscopes, telescopes, cameras, photoelectric cells, and sensitive balances are a few examples. As a result of the evidence accumulated through the use of such instruments, we accept the existence of X rays, molecules, germs, high-frequency sound, and other realities which we cannot see, feel, or hear directly with our senses. Even scientific instruments are not perfect, however. Thermometers, electric meters, and similar measuring devices must be calibrated to reduce possible errors. Glass lenses must be color corrected to prevent the formation of color fringes around the image. The goal always is to obtain the facts, for generalizations and conclusions can be no more trustworthy than the data from which they are derived.

If several people were given the same set of data and were asked to draw conclusions from the data alone, do you think they would all agree? Possibly so, but probably not. Since this step in scientific problem-solving depends on subjective judgment and one's ability to compare, evaluate, and see relationships among facts, obviously there is likely to be wide variation among individuals. One's ability to draw valid, trustworthy conclusions from data can best be improved by training and experience.

The test of a conclusion is whether it really works in practice—whether it forms an adequate solution to the original problem. A further, still more reliable test is to determine the usefulness of the generalization in predicting what ought to happen in new situ-

ations to which it applies. If the predictions are verified by further testing, more confidence may be placed in the conclusion; if not, it may be necessary to start anew the entire sequence of problem-solving procedures.

The scientific attitudes are numerous, but specific. Attitudes are points of view, or ways of looking at things; they describe how we "feel" about matters. All people have attitudes, and there are all kinds of attitudes. Scientific attitudes, however, are based on facts and reason rather than on prejudices, traditions, hearsay, intolerance, and blind imitation of others. A person whose attitudes would be characterized as scientific might be described as follows:

1. He believes in cause and effect—that is, that there is a cause for everything that happens, even though the cause may not be apparent. He does not believe in signs or superstitions, and he does not "trust to luck."

2. He does not believe, however, that just because two things occur together there is a connection between them; it may be mere coincidence.

3. He seeks the truth. He does not allow his personal desires, wishes, and expectations or the lure of great wealth to influence his search for truth. The scientist has a zeal and a passion for the whole truth.

4. He patiently makes observations and collects data over as long a period of time as is necessary to get sufficient evidence to justify drawing a conclusion. Until sufficient evidence is available, he suspends judgment. He does not jump to hasty conclusions.

5. He realizes that many conclusions are only tentative and is willing to modify them in the light of new evidence—but he must be shown.

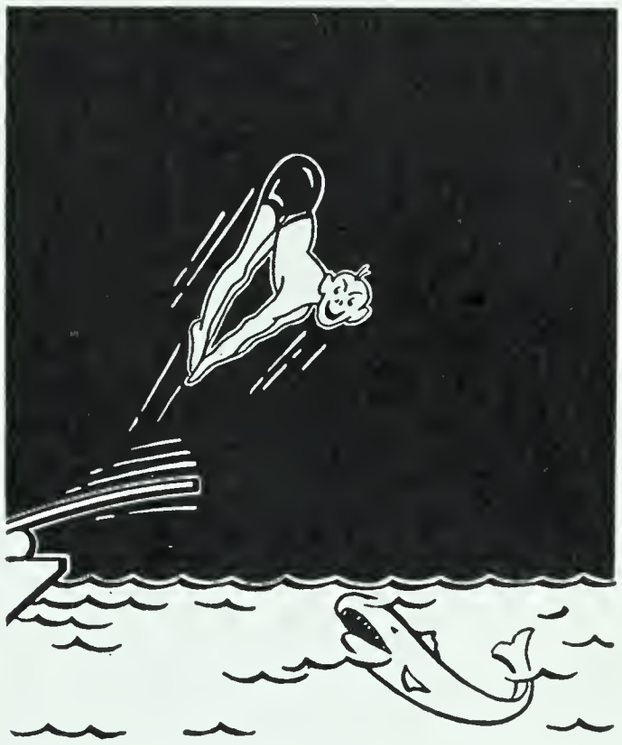
6. He is willing to listen respectfully to the other fellow's point of view and to accept the findings of other investigators if he has confidence in their ability and reputation. He realizes his own limitations and knows that he cannot discover everything for himself.

7. He realizes that man may not know the complete story and that our ideas of truth change. The truth prevails, however, no matter what our beliefs may be. For hundreds of years people believed the earth was flat, but that did not make it so. Columbus, Magellan, and others dared to question this belief and gathered enough evidence to the contrary to cause man to change his ideas about the shape of the earth.

8. He shares his knowledge and his experiences with others, frequently at the loss of large personal financial gain. Louis Pasteur and Marie Curie could have made millions out of their scientific discoveries, but they preferred to act in the scientific spirit—they gave their knowledge to the world.

9. He does not believe that "what you don't know won't hurt you." He believes that it is important to know the truth, even if you do not like it.

10. He believes in controlled experimentation as the safest guide to truth; he uses trial-and-error procedures only when necessary and has no respect for blind hit-or-miss methods.



"What you don't know won't hurt you."

The scientific habit is not automatic—you must make it work. It is helpful to read about the scientific method in books, but that is not enough; you must also *do* something about it. Try to practice the scientific method in reaching decisions in your daily problems. Throughout this book, frequent mention is made of scientific methods and attitudes, and numerous specific examples are given. Try to see how these ways of thinking and acting can be adapted to your own use in solving the problems of daily living. It is hard and it takes courage to be scientific and to live according to the scientific spirit, but it is worth the effort.

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. With what does physical science deal?
2. How can physical science be of direct benefit to you?
3. Why do you think physical science will be an interesting course?
4. Do you agree with John Dewey's statement? Why?
5. How do you react to Elliot R. Downing's statement? Why?
6. How does "armchair philosophy" differ from the scientific method? Is "armchair philosophy" practiced today? If you think so, cite examples.
7. Can you always rely on your senses? Give examples.
8. How has man aided and extended his senses?

9. Explain what is meant by the statement, "The scientific habit is not automatic."

10. An "upside-down" hill was reported in a town in Massachusetts. An automobile when stopped at the bottom of it and put into neutral would roll on up; when driven down the hill and put into neutral, the car would roll back up to the top again. Hundreds of people flocked to see the strange hill and offered many explanations for it. A town official said, "Well, this beats all; it's anybody's guess what causes it." Criticize his statement and explain your own hypotheses.

11. Can you think of any situations that might arise in which the scientific attitudes should be suspended in favor of others? Explain.

12. Science has made it possible to produce, preserve, and transport an adequate food supply. Why are some people ill-fed and others actually hungry?

13. Do you believe that the peak of scientific discovery and invention has been reached and perhaps passed, or do you think as many or more scientific wonders still lie ahead? What possible new discoveries can you think of?

14. Discuss each of the following statements from the standpoint of scientific method or attitude:

(a) If you stare at a person's back, he will turn around and look at you.

(b) Fat people are always good-natured.

(c) Patent medicines are consumed mostly by ignorant people.

(d) A scientist insists upon facts as a basis for drawing conclusions.

(e) The tested facts of today will withstand the acid test of time and remain as facts in the future.

(f) There are no exceptions to natural laws.

(g) The almanac weather predictions are scientific in the sense that they are based upon the usual weather conditions for each period.

(h) In using the scientific method, you first form a conclusion and then seek facts and other evidence to support it.

(i) The most trustworthy scientific facts and principles are really statements of the opinions and beliefs of eminent scientists.

(j) Natural laws can be discovered only by applying the scientific method.

(k) Scientists are unanimous in their acceptance of the outstanding scientific theories.

(l) A forked willow branch can be used by some individuals to indicate the presence of underground water.

15. How would you apply the scientific method to solve these problems?

(a) Which is hotter, steam or boiling water?

(b) Which is colder, ice or ice water?

(c) Is there any difference between the freezing point of water and the melting point of ice?

(d) Which will form ice first if cooled under identical conditions, (1) water near the boiling point or an equal quantity of water at room temperature; (2) tap water or an equal quantity of water which has been previously boiled and cooled to the same temperature?

WORD LIST

Here is a list of words whose meanings you ought to know. A similar list of words that are much used is given at the end of each unit. Study them carefully, because your success in the course will depend to a large degree on how well you master the vocabulary.

physical science
law
principle
scientific method
hypothesis
observation
experiment
data
inference
conclusion
scientific attitude
superstition
tradition
unfounded belief
ignorance
skeptic
hearsay
prejudice
propaganda
intolerance
gullible
cause and effect
coincidence
suspended judgment
trial and error

INTERESTING THINGS TO DO

1. Make a list of ten "how" or "why" questions about physical science not given thus far in the text.
2. Read the titles of the units and problems given in the Table of Contents and prepare a list of twenty-five problems of daily living not given in the text. Compile a master list of all the different ones brought in by other members of the class.
3. Repeat Galileo's experiment on falling objects and report your results to the class.
4. Begin making a collection of newspaper clippings to show that superstitions and other nonscientific beliefs still persist in the world.
5. Make a scrapbook with a section set aside for each unit in the course, and begin a collection of newspaper articles and pictures about "physical science in the news."
6. Make a list of as many devices as you can think of which were not known or were not in common use twenty-five years ago.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Select one or more vocations from the various fields of science, and investigate the nature of the work, the qualifications and training

necessary, the remuneration, and the opportunities for advancement.

2. The history of astrology.
3. The methods and contributions of the alchemists.
4. Witchcraft in the United States.
5. The Duke University experiments on extrasensory perception.
6. The persecutions of early scientists.

INTERESTING BOOKS TO READ

Curie, Eve, *Madame Curie.* Doubleday, Doran and Company, New York, 1937. Outstanding for its portrayal of the scientific spirit.

Davis, Watson, *The Advance of Science.* Doubleday, Doran and Company, New York, 1935. A fairly complete record of the progress science has made in all fields. Clearly written and well illustrated.

Davis, Watson, *Science Picture Parade.* Duell, Sloan, and Pearce, New York, 1940. A presentation of several hundred most excellent photographs which have appeared on the covers and in the pages of *Science News Letter.*

Furnas, C. C., *The Next Hundred Years.* Reynal and Hitchcock, New York, 1936. A very readable account of the "unfinished business of science."

Harrison, George R., *Atoms in Action.* William Morrow and Company, New York, 1939. An interesting survey of the contributions of physics to everyday living.

Jaffe, Bernard, *Crucibles.* Simon and Schuster, New York, 1930. Well-told accounts of the lives and achievements of the great chemists.

Kaempffert, Waldemar, *Science Today and Tomorrow.* Viking Press, New York, 1939. A popular interpretation of science with emphasis on its social aspects and the significance of the scientist and technologist in society.

Kruh, F. O., Carleton, R. H., and Carpenter, F. F., *Modern-Life Chemistry.* J. B. Lippincott Company, Chicago, 1941. A standard textbook of high school chemistry which will prove helpful as a reference.

Pupin, Michael, *From Immigrant to Inventor.* Charles Scribner's Sons, New York, 1923. A great man's inspirational story of himself and other great men and of the idealism of science.

Slosson, Edwin E., *Creative Chemistry.* D. Appleton-Century Company, New York, 1923. A classic among popularizations of science.

Stewart, Oscar M., Cushing, Burton L., and Towne, Judson R., *Physics for Secondary Schools.* Ginn and Company, Boston, 1941. A standard textbook of high school physics which will prove helpful as a reference for many of the units in this book.

Wendt, Gerald, *Science for the World of Tomorrow.* W. W. Norton Company, New York, 1939. One of the best popularizations of science. The author analyzes our civilization and suggests how science may help to build a better one for the world of tomorrow.

rap Atop Roof ses Sun's Rays o Heat House

.T. Scientists Store Solar Energy in Basement for All-Year Air Conditioning

AMBRIDGE, Mass., Nov. 4 (AP).—achusettes Institute of Tech-gy engineers said today that planned to trap some of the s heat and hoard it for p ssible in winter house heating, sum- air conditioning, and power ration.

iation Gasoline tput Increased New Process

"Alkylation" Also Reduces Cost of 100-Octane Product

new refining process which es, if desired, the refinery out- of aviation gasoline of 100- ne value, and at less cost, has developed and is under license veral of the world's major oil panies, it was learned today. The ess, called "Alkylation," permits omy through eliminating the costly operation of hydrogena-

High Fuel Cost CanBeReduced By Insulation

Reports by Housewives and T. V. A. Engineers Prove Big Savings Are Made

To a large degree, the problem

UNIT ONE FIRE, FUELS, AND HEAT

Boosts Gasoline Output

w Cracking Process Helps U. S. and Increases Percentage of Use from Crude Oil

2 Ensigns Save Woman's Life

Chop Down Door of Gas-Filled Apartment

Two Naval Reserve ensigns mod- estly accepted congratulations from

Explosion Kills Four Brothers Cleaning Garage With Benzine

4 Killed, 17 Hurt in Oil Blast

U.S. Told to Avoid Petroleum Waste

Russia Shown Second Largest Producer

New High Test Gas Perfected

Development of a new process for manufacture of aviation gaso-

0 Rules for Tending Furnace Proposed o Save Nation 15 Million in Yearly Coal Bill

ASHINGTON, Sept. 5.—The eau of Mines estimated today $150,000,000 could be cut n America's annual bill by er furnace maintenance. The eau offered 10 rules:

elect type and size of fuel fully. It usually pays to ex- ment with a few different s.

Keep plenty of fuel in the fur- nace.

Keep air entering ash pit or furnace under control.

Before shoveling fresh coal into the furnace, hoe up the fuel bed so that some hot fuel will remain at the top after firing.

Where there is much flaming at the top of the fuel bed, admit some air over the fire through the damper on the firing door.

Shake down the ashes gently and stop when any red particles fall into the ash pit.

Do not stir fire with a poker.

Do not let the ash pit remain full of ashes.

Keep all heating surfaces clean.

Keep furnace pipe and chim- ney free from obstructions and air leaks.





Unit One

FIRE, FUELS, AND HEAT

The march of civilization began when man learned to make adjustments to fire, fuels, and heat. Without a knowledge of how to start and control fires, man could not have progressed beyond the stage of savagery. Primitive peoples recognized their inability to get along without heat and light and expressed this feeling of dependence in their religions by making the sun a god, or goddess, a mighty being who could influence the welfare of mankind for good or evil. This feeling of dependence was lessened somewhat when man's natural curiosity led to the discovery that fires could be built and used for such practical purposes as cooking his food and providing heat and light for his crude dwelling. Little did he realize at that time that wood and other common fuels represent vast stores of sun energy that have been absorbed and stored by growing organisms over varying periods of time.

In modern life, fire and fuels present many wonders and dangers, and they raise numerous complex problems. Fuels are burned in special devices in the home for the purpose of liberating heat to cook our food, to provide hot water, and to keep us warm and comfortable. Beyond the home we find that practically every factor of our present age depends upon fire, heat, and fuels. The manufacture of cement, steel, and glass; the production of electricity; and transportation by automobile, train, steamship, and airplane—these are just a few examples.

On the other hand, fires cause enormous losses through the destruction of life and property. Gas explosions, grease fires, defective flues and over-heated stoves, and spontaneous combustion are common sources of danger in the home; in mining and industry, the possibility of dust explosions is an added hazard. Disasters like these can be prevented or brought under control by learning about the nature of various types of burning and applying this knowledge in an intelligent manner.

In this unit, we shall learn how man at the present time has solved the problems met in obtaining and utilizing the most basic of all forms of energy—namely, heat.

Photos courtesy American Petroleum Institute (top); Norfolk and Western Railway

Problem 1: How does man obtain heat?

Man taps a number of sources to obtain the energy which he uses as heat. The fires caused by lightning and erupting volcanoes taught primitive people that the materials of our environment can be divided into two classes: (1) those that will burn and (2) those that will not burn. Charred remnants found in excavations reveal that very early man built fires to heat his cave dwelling and to cook his food.

Wood, the first fuel, is still sometimes used in places where it is abundant and cheap. For thousands of years it satisfied man's need for stored heat and energy, but the coming of the machine age, with its increased demand for energy to run the machines, found wood inadequate. Coal and oil, as we all know, are now the common fuels used for the production of heat.

• HISTORY OF FIRE-MAKING

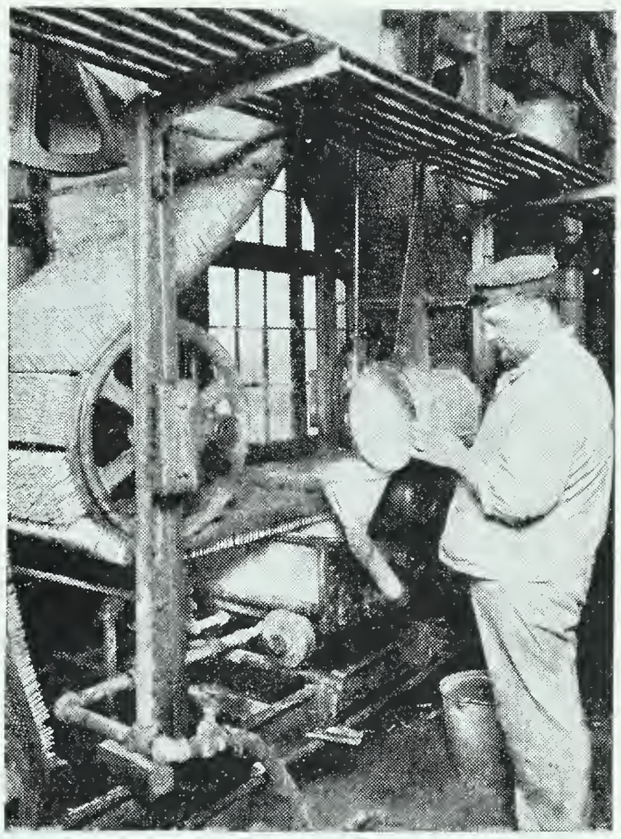
Relics of the past point out that fire-making remained until comparatively recent times a difficult task. How to reach the kindling temperature of the fuel with ease was handed down as a problem for modern chemistry to solve. Primitive people learned that fire could be obtained by patiently rubbing together sticks of dry wood until enough heat developed to ignite leaves, dried moss, or other tinder. Later on, the process was speeded up by adapting the bow for twirling one piece of wood against another. Some primitives never did reach this second stage of development. Such were the methods the early settlers found the Indians using when they came to the American shores. Indeed, the settlers were dependent upon the crude method of striking together flint and steel and igniting materials of fairly low kindling temperature with the resulting sparks.

It was a great step forward when in 1810 Chancel, a Frenchman, invented a chemical match. It consisted of a stick of wood to the tip of which was glued a mixture of powdered potassium chlorate and sugar. The heat of the reaction which ensued when the tip was dipped into concentrated sulfuric acid was sufficient to ignite the sugar and ultimately the wood.

Chancel's match was in use but a short time when the first friction match was invented in 1827 by John Walker, an English apothecary. The tip of the match consisted of potassium chlorate, antimony sulfide, and starch. Its advantage over the earlier one

lay in the fact that it could be lighted by drawing it between folds of sand paper, thus eliminating the danger and inconvenience in handling sulfuric acid. This match was not satisfactory, because too much pressure was needed to light it.

Later a French student of chemistry discovered that a more easily ignited match could be made by substituting white phosphorus for antimony sulfide in the tip of the match. Despite certain advantages, this match brought about an acute health problem. Workers by the hundreds in factories where these matches were made became poisoned and developed "phossy jaw," a dreadful disease characterized by the rotting away of the jawbones. For this reason the use of white phosphorus in matches has been made illegal or taxed until unprofitable in all civilized countries.

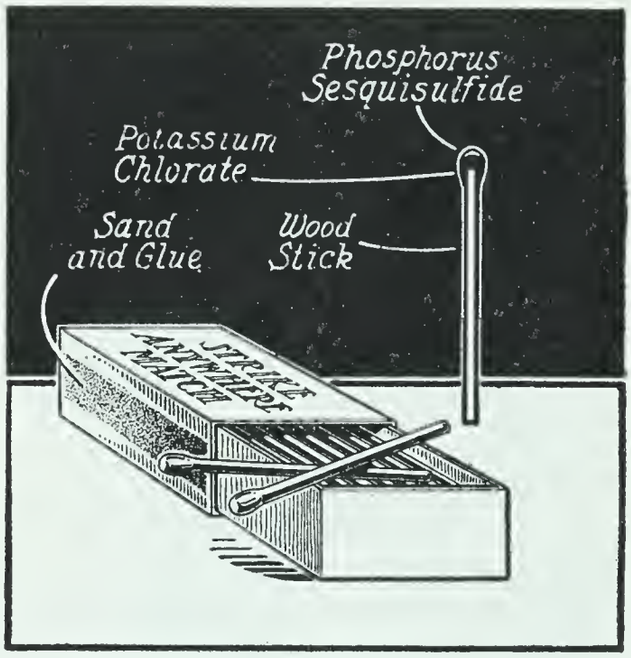


Brown Brothers

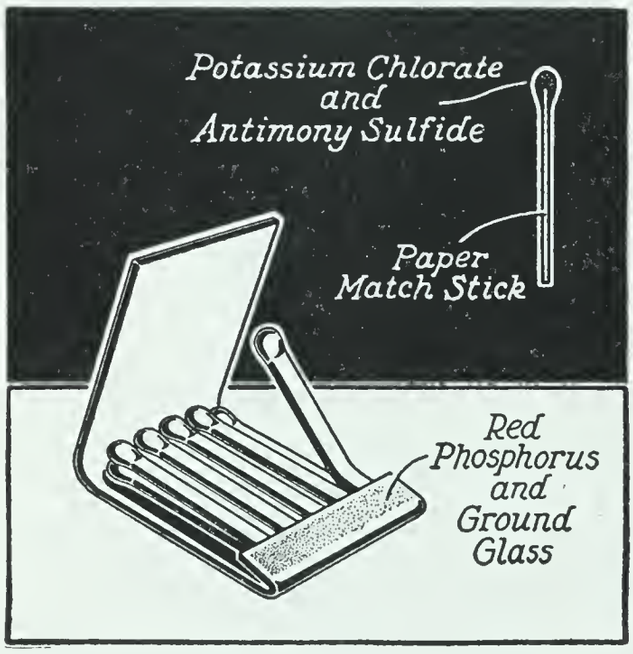
Millions of matches are made each year by machines like this one. Can you figure out how it works?

Today, the ordinary "strike anywhere" match consists essentially of the following materials: (1) a substance which is easily ignited by friction, such as phosphorus sesquisulfide; (2) an oxidizing agent, such as potassium chlorate; (3) material to provide friction, such as ground glass; and (4) glue to bind these materials together. In striking the match, the phosphorus sesquisulfide is ignited. The potassium chlorate, by its oxidizing action, causes vigorous burning for a brief interval—long enough to provide the heat necessary to ignite the wood. The materials described constitute the head of the match. The phosphorus sesquisulfide, for obvious reasons, is placed at the extreme tip of the head. The wood sticks are usually subjected to a preliminary treatment by dipping them into paraffin to make them burn easily.

In 1844, another step was taken toward a more effective adjustment to the problem of safely starting a fire. This time it was the invention of a match that could not be struck everywhere—a safety



How does "striking" this kind of match cause it to ignite?



What are the safety features of this kind of match?

match. The inventor, a Swedish professor, omitted phosphorus from the head of the match; instead, he applied it to a strip of sandpaper so the match could be ignited only by striking it on this prepared surface. Modern safety matches have a head which consists of antimony sulfide and an oxidizing agent, such as potassium chlorate. They cannot be conveniently lighted except on the prepared surface provided on the side of the box or at the bottom of the book in which they are packed. The material on this prepared strip is a mixture of nonpoisonous red phosphorus, ground glass, and glue. Because of much careless disposal of matches, the lower part of the stick of both safety and "strike anywhere" matches is usually dipped in a fireproofing material, such as ammonium phosphate, to prevent smoldering or afterglow.

• THE MYSTERY OF FIRE

Until less than two centuries ago, the true nature of burning remained a mystery. One of the first explanations to receive serious consideration was advanced in 1717 by the German physician, Stahl, and was widely known as the *phlogiston theory*. It was a good theory in some respects, but several weaknesses finally resulted in its downfall.

Among the *facts* which any theory of burning had to account for were two outstanding observations: (1) almost all burnable materials had to have air in order to burn; (2) metals gained in weight

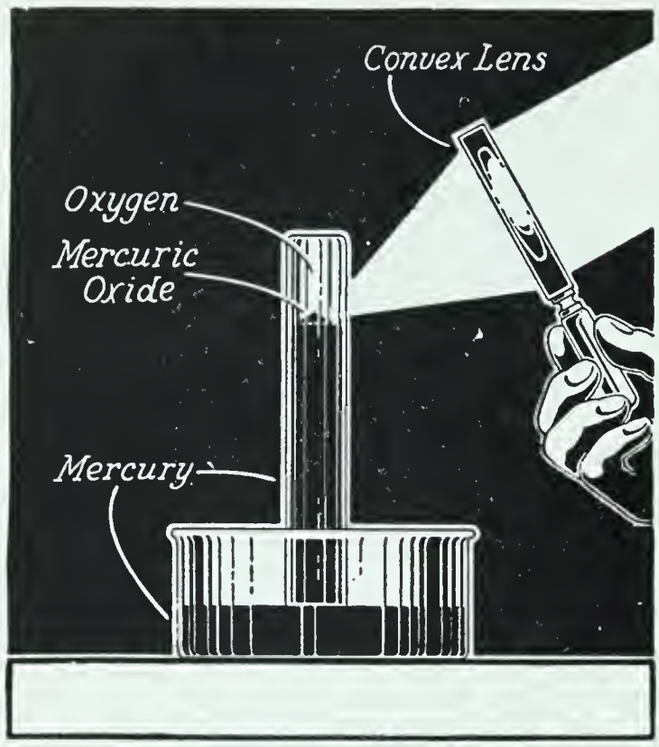
when they were heated in air but remained unchanged when heated out of contact with air.

According to the phlogiston theory, every burnable material contained phlogiston, and this was believed to escape when the material burned. This escape accounted for the crackling and fuming and smoking of a fire. Things which would not burn were believed to contain no phlogiston. To explain why air was necessary to burning, this theory held that phlogiston had to have air to "escape into" or "unite with" upon leaving the burning material.

The phlogiston theory finally was abandoned because it could not adequately explain the fact that metals gain in weight when heated in air. The followers of this theory explained such gain in weight by assuming that phlogiston had negative weight—that it weighed less than nothing—and that the more phlogiston that escaped, the more the burning object weighed. The fallacy of such reasoning is obvious.

The discovery of oxygen prepared the way for the development of the modern explanation for burning. In 1774, while experimenting with gases, or "airs," and the effect of heat on various materials, Joseph Priestley floated a red powder at the top of a column of mercury in a tall cylinder, the mouth of which was immersed in a dish of mercury. He heated this red powder, which we now know as *mercuric oxide,* by the aid of a strong burning glass and discovered that a colorless gas was evolved. He studied its properties and was surprised that a candle burned in it with extreme vigor. Because things burned with such intensity in his new gas, Priestley thought that he had prepared air containing no phlogiston; hence, he called it "dephlogisticated air." In his book entitled *Experiments and Observations on Different Kinds of Airs,* Priestley wrote, "I have gratified my curiosity by breathing it. The feeling of it to my lungs was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy for some time afterwards. Hitherto, only two mice and myself have had the privilege of breathing it." Priestley evidently did not realize the importance of his discovery.

Karl Wilhelm Scheele, a Swedish chemist, is also given credit for the discovery of oxygen. From a study of his notes and letters, we now know that he discovered oxygen at least a year before Priestley did. Because of a delay on the part of the publisher in printing the report of his findings, his discovery was not made

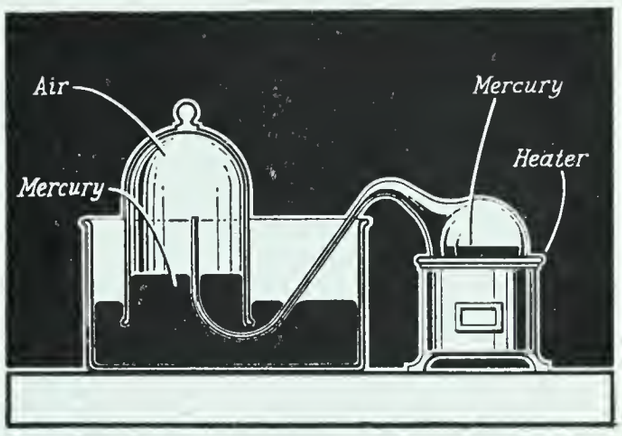


Method by which Priestley discovered oxygen.

known until after that of Priestley. It was Priestley's work, therefore, which really influenced the subsequent development of the true explanation for burning.

The true explanation for burning was finally developed by Antoine Lavoisier, a Frenchman, as a result of two brilliant experiments. Lavoisier advanced the hypothesis (a scientific "hunch") that burning was not the escape of phlogiston from a material but rather the uniting of the material with a part of the air in which it was burning. He also suspected that this part of the air was identical with the gas which Priestley had recently discovered. In order to test these hypotheses, Lavoisier conducted two experiments. The story of these experiments is a classic portrayal of the scientific method of investigation and attitude of mind.

In his first experiment on burning, Lavoisier put a weighed amount of tin into a glass flask and carefully sealed the neck of the flask so that no air could enter or escape during the experiment. He weighed the flask and its contents and then heated it carefully until the tin appeared to be converted into a white powder. After waiting for it to cool, he checked the weight again but found no change. An inrush of air when the seal was broken indicated a partial vacuum within. Another weighing showed that the weight was now greater. When Lavoisier removed and weighed the powder resulting from the heating of the tin, he found that its weight was greater than that of the original tin by precisely the same amount that the flask had increased in weight when the seal was broken. Lavoisier concluded that the observed change in the tin had been caused by its chemical union with at least part of the air within the flask. He decided later that only a portion of the air was involved, because when he used a large amount of tin, some of it remained unchanged although all of the air had not been consumed.



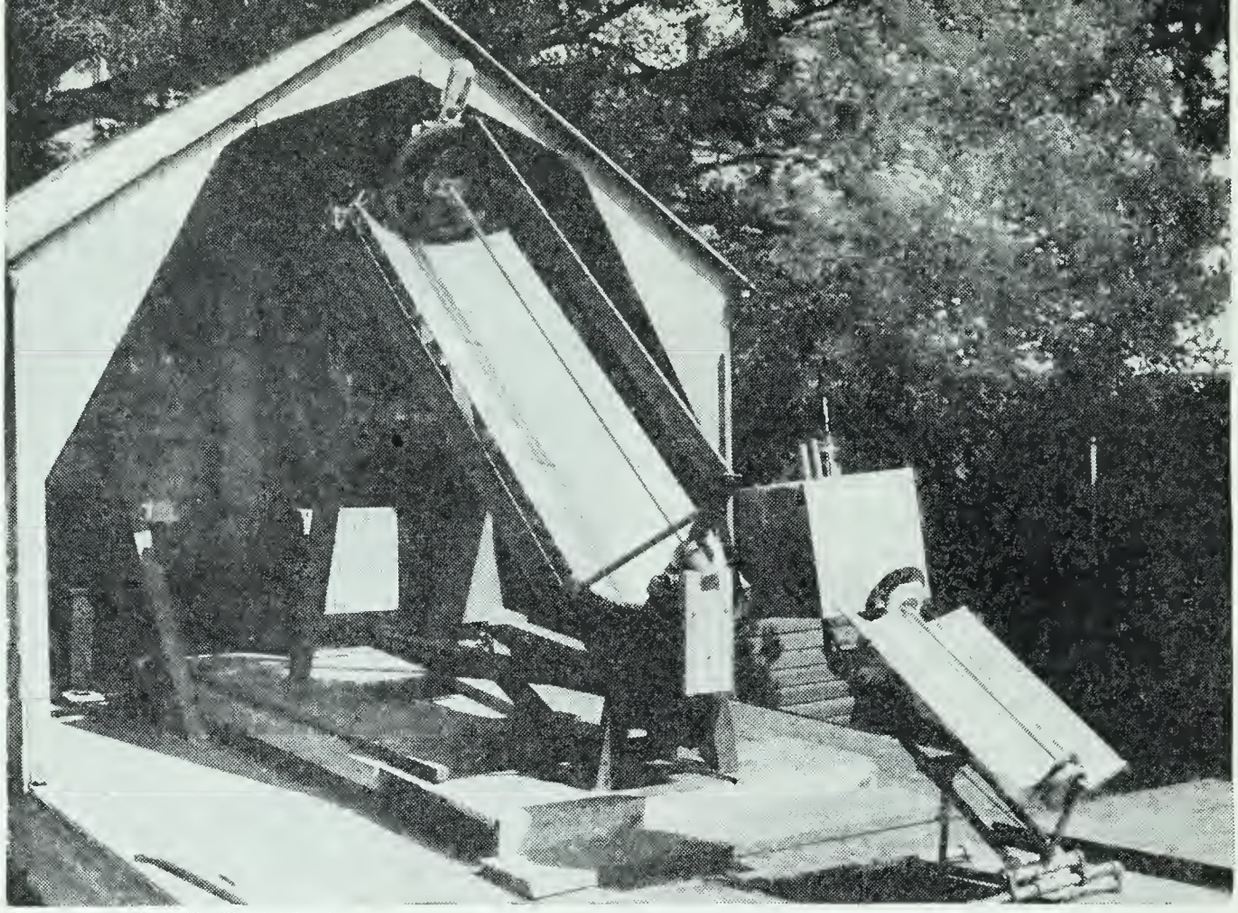
To test his hypotheses about the role of oxygen in burning, Lavoisier conducted his famous "twelve-day" experiment with apparatus like this. Can you explain what he did?

Next, Lavoisier confirmed his tentative conclusion by another experiment based upon the one in which Priestley had discovered oxygen. Shortly before this, Priestley had visited Lavoisier and explained how he obtained his "dephlogisticated air." Taking advantage of this information, Lavoisier heated some mercury for twelve days in a measured volume of air until a considerable amount of red mercuric oxide appeared on its surface. After recording the decrease in the volume of air, he removed the red powder and decomposed it by heating it at a higher temperature. As Lavoisier anticipated from Priestley's account, a gas was liberated and mercury deposited. He collected the gas and found that its volume was equal to the decrease in the volume of the original air used. Later, he named this gas *oxygen,* meaning in Greek "acid-producer," because he erroneously believed it to be a constituent of all acids.

These experiments thoroughly convinced Lavoisier of the role played by oxygen in burning. Man had finally found out in 1777 that burning was a process in which some combustible material united with oxygen and that the increase in weight of the burned material was equal to the weight of the oxygen lost by the air.

Lavoisier next busied himself with experiments to test the implications suggested by his new theory. The results were so conclusive that scientists everywhere began to recognize its worth. There were notable exceptions, however; among them was Joseph Priestley, who remained to the end an ardent supporter of the phlogiston theory.

Besides the fuel and kindling temperature, the other essential for combustion is an adequate supply of oxygen. When we use the expression, "an adequate supply of air," we really mean the 21 per cent of oxygen by volume which it contains. Anything which will not combine with oxygen will not burn in air. Ordinary burning, such as that of a candle, will not take place in air made up of less than about 15 per cent to 17 per cent oxygen by volume. On the other hand, combustion may be promoted by



Courtesy Dr. C. G. Abbot

Here is a method of harnessing the sun with aluminum mirrors. Dr. C. G. Abbot's flash-boiler solar engine of 1/5 horsepower and his toy solar cooker and impulse engine in the foreground are constructed to produce steam within five minutes after exposure to the sun. Can you figure out how it works?

increasing the supply of oxygen. Sometimes this is done by using blasts of air, as in the blast furnace for obtaining iron from its ore, or by substituting oxygen for air, as in the oxyacetylene blowtorch. Anything which burns in air will burn at a faster rate in oxygen, and some materials, iron wire for example, which do not burn in air can be burned in an atmosphere of this gas.

• OTHER SOURCES OF HEAT ENERGY

Beginning with the Industrial Revolution, man's increasing use of machines and the resultant need for power created an ever-increasing demand for heat energy. Other sources to supplement the burning of fuels have of necessity been developed. Furnaces heated by electricity are now widely used in industry. The electricity is transformed into heat either by producing an arc or by passing it through metal in the form of wire or ribbon which offers much resistance to its flow. The arc furnace enables man to obtain higher temperatures than those obtained in resistance furnaces or in furnaces designed for the combustion of fuels. In industry, electric furnaces produce graphite, carborundum, and considerable quantities of high-grade steel; while in the home, the

electric stove, iron, and toaster are familiar devices for the production of heat from electricity.

Sometimes advantage is taken of the fact that heat is evolved when gases are compressed. The Diesel engine makes use of this principle to ignite its fuel and air mixture and in this way eliminates the elaborate ignition system of the gasoline engine.



Courtesy General Motors Corporation

Despite scientific progress, modern man, like his primitive ancestors, is dependent on the sun, directly or indirectly, for light and heat.

Attempts have been made to use the sun's energy directly in various types of solar engines. Some idea of the amount of energy coming to the earth from the sun can be obtained from the following estimate by C. G. Abbot, secretary of the Smithsonian Institution: "The state of New Mexico alone receives nearly 100 times as much solar heat as the combined consumption of coal, oil, and hydroelectric energy in the United States, if expressed in heat units." Engines which Abbot has designed indicate that as much as 15 per cent of available sunlight can be ultimately used in other forms. Concave mirrors focus the rays of the sun upon tubes of liquid; heat is absorbed which is then used for the generation of steam.

One of the chief difficulties met with in solar engines is their change in efficiency with changes in the intensity of the sun's rays. Naturally, the hours during which they can operate are limited. The sun-beaten regions of the earth hold the most promise for their successful operation. At the present time experimentation with solar engines is of interest because of the possibility of its providing an adequate source of energy when man has exhausted the coal, oil, and other fuel reserves now available.

In a few places it has proved profitable to collect and make use of steam and hot water coming from cracks in the earth's crust. Such sources of energy are usually found in mountainous regions like those of the Italian peninsula where volcanoes are, or have been, active.

Although heat is obtained from many sources and higher forms of energy, such as electricity, are frequently transformed into heat, fuels are still the most economical source of heat, and hence most widely used. But practically all of the energy used on the earth has originally come from the sun, no matter what may be its immediate source.

Exercises for Problem Study and Review

1. How long have chemical matches been used? How were kindling temperatures produced before the invention of the match?
2. Why is white phosphorus no longer used in making matches?
3. What materials compose the various parts of the "strike anywhere" match? What is the function of each part?
4. Describe the construction of the safety match. What measures have been taken to make it "safe"?
5. What three essentials must be provided in order to build a fire?
6. How did the phlogiston theory explain burning? Can a theory be wrong? When does a hypothesis become a theory? Why was the phlogiston theory finally abandoned? What is the purpose of a theory?
7. Explain why it can be truly said that Priestley did not realize the importance of his discovery of oxygen.
8. For how many years has the true explanation of burning been known? Who developed it?
9. How much of the air is oxygen? How can this be proved?
10. What is the true explanation for burning?
11. How can the rate of combustion be speeded up?
12. In what two ways can heat be obtained from electricity? Name three devices that are used in the home or shop for this purpose.
13. How does a solar engine work? What are its advantages and disadvantages?
14. What other natural sources of heat energy has man tried to harness?
15. Trace back to its source the heat energy used in toasting a slice of bread.

Problem 2: How does man provide an adequate fuel supply?

Scientific progress through the ages has provided modern man with a variety of fuels from which to select. When the term "fuel" is mentioned, most people immediately think of fuel for the pur-



Courtesy The Philadelphia and Reading Coal and Iron Company

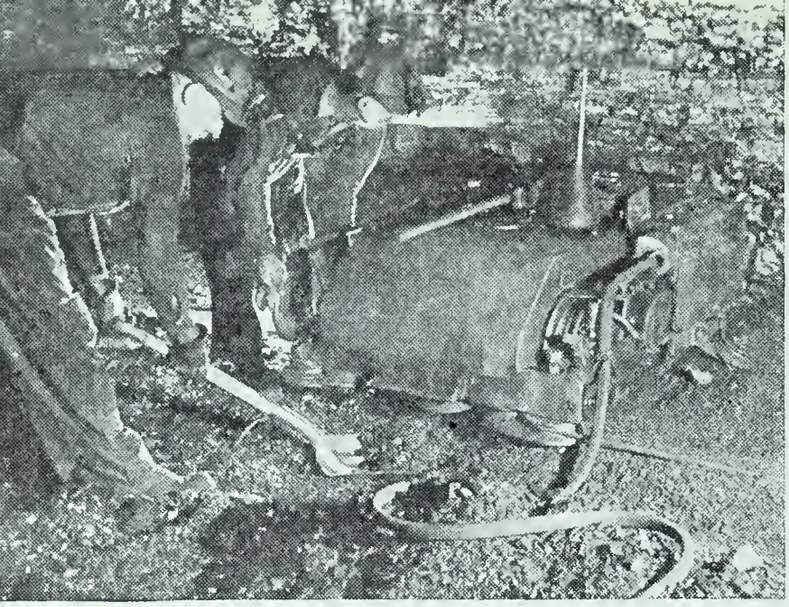
In this view of anthracite-coal mining, each seam represents what was once a vast collection of trees and other forest growth. How do you think the rock between the seams was formed?

pose of heating their homes. Likewise, they think of the particular fuel which they are accustomed to use; but, of course, all people do not use the same one. Factors which govern the choice include locality, climate, cost, and type of heating plant. The fuel chosen for use nowadays is usually wood; bituminous or subbituminous coal; anthracite coal; coke; or some variety of gas or oil.

• SOLID FUELS

The first fuel used by man was undoubtedly wood. Today it is little used for heating residences, except in localities where it is plentiful and the cost of other fuels is high. A wood fire in an open grate or fireplace presents a very cheerful appearance, and for this reason many people burn some wood even in localities where other fuels are more economical. But the amount of wood available for fuel is becoming less and less. Moreover, wood is not a very desirable fuel because of its high water content—usually about 15 to 40 per cent by weight. This causes the quantity of heat obtainable by burning a pound of wood to be quite small in comparison with the heat obtainable from other fuels. Some wood is converted into charcoal by heating it in the absence of air. This process gives a fairly useful solid fuel and also leaves as valuable by-products wood alcohol, acetone, and acetic acid.

Coal is another solid fuel which has been known since remote times. In a book written about 315 B.C., Theophrastus, a Greek philosopher, described a kind of "stone" that would kindle and



Courtesy *Coal Age*

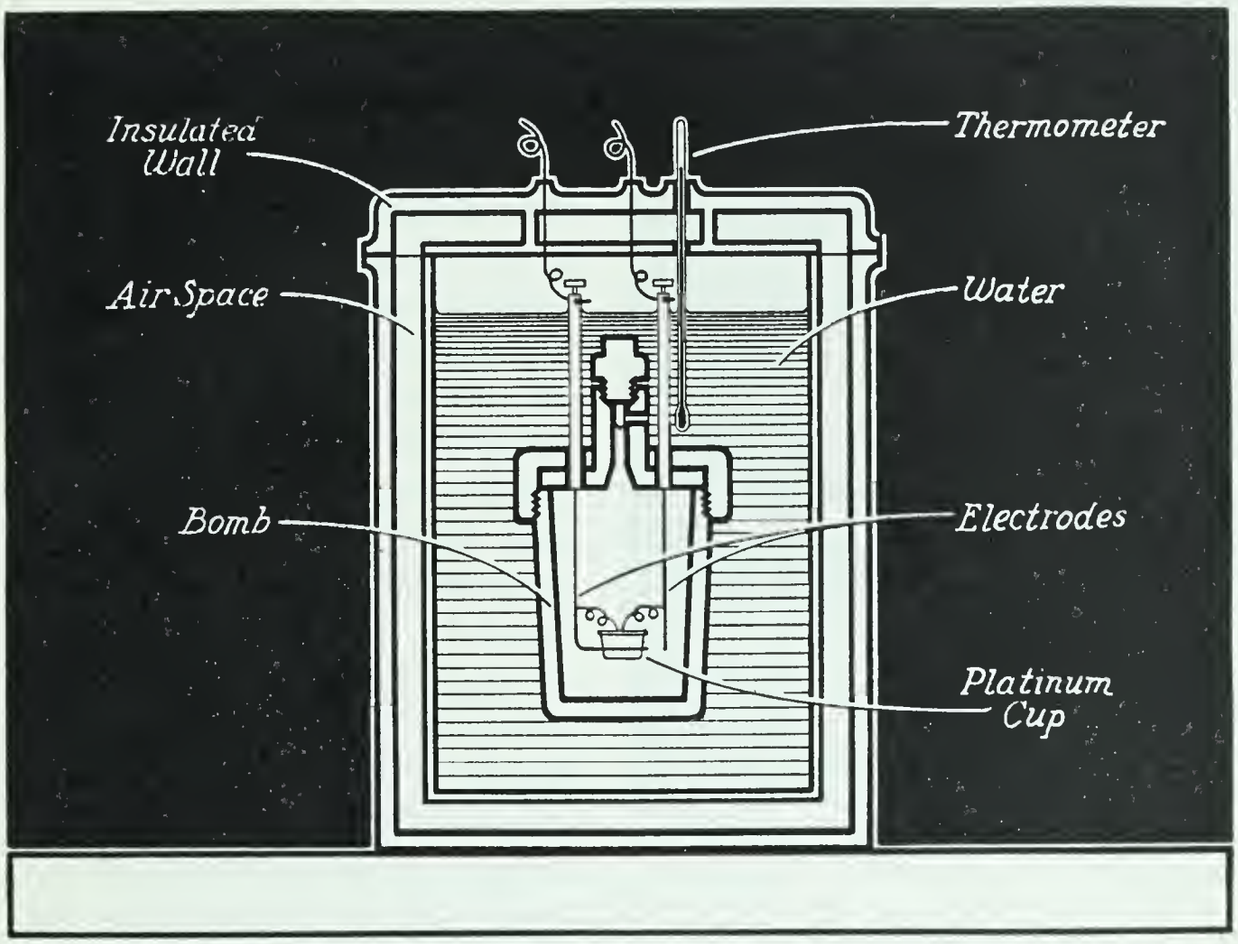
These miners are operating a cutting machine far beneath the earth's surface while mining coal. How necessary is this source of solar energy to our present industrial civilization?

burn. In all probability he referred to coal. The existence of coal in our country was first reported by Hennepin in 1679; he noticed it along the Illinois River. The mining of coal was first carried on near Richmond, Virginia, about 1749.

Coal that lies near the surface is usually mined by strip mining; that is, the overlying earthy material is removed by steam shovels and the coal is left exposed, ready to be removed by blasting and shoveling. This is the safest and cheapest method of mining. Under other favorable conditions, coal can also be mined by running tunnels or drifts horizontally or slanting from the surface of the earth to the coal seam. When the coal is situated far below the surface, vertical shafts are sunk to it and drifts are run out in various directions and at various levels.

Much of the work of handling coal is now done by machinery. Mines have been electrified, and this one advance has greatly promoted efficiency in mining operations. Compressed-air drills make holes in the roofs and sides of the mine chambers. These holes are loaded with explosives which bring down tons of coal and some rock. This material is loaded into cars, sometimes by hand but often by machinery, and is hauled to a shaft by mules or electrically driven cars. Here it is lifted to the surface by hoists driven by steam or electricity. At the surface, the coal is cleaned, sorted to size, and shipped.

Bituminous coal has a slightly higher heat value than anthracite, but otherwise it is generally less desirable as a domestic fuel. An anthracite coal fire is easy to control and may be left for long periods of time without attention. Soft coal is difficult to fire so as to obtain complete combustion; when incomplete burning takes place, a smoky, dirty fire results which forms soot in the chimney and produces gases that are explosive and poisonous. Soft coal also leaves more ash than anthracite. In spite of these drawbacks, soft coal is the most widely used domestic fuel because it is cheap. It is less costly to mine and prepare, and because of its wide distribution, the haul is usually shorter and therefore less expensive.



The heat values of foods as well as fuels are determined by means of the bomb calorimeter.

Industry and transportation agencies also use large amounts of soft coal, because it combines low cost and high heat value.

The heat value of a fuel is ordinarily determined by measuring the heat given off when a definite amount of it is burned. The test sample is burned inside a steel bomb surrounded by water. Complete and rapid burning is assured by filling the bomb with oxygen under pressure. The heat given off by the burning fuel raises the temperature of the water surrounding the bomb. From the weight of fuel burned, the amount of water heated, and the rise in temperature of the water, the number of heat units that one pound of the fuel will generate can be calculated. The unit generally employed is the British thermal unit, abbreviated B.T.U.; it is the quantity of heat required to change the temperature of one pound of water one degree Fahrenheit. Different kinds of coal vary in heat value, some ranging as low as 8,500 or 9,000 and others as high as 14,700 British thermal units per pound. Consumers of very large quantities of coal ordinarily buy it on the basis of its heat value as determined by laboratory tests.



Ewing Galloway

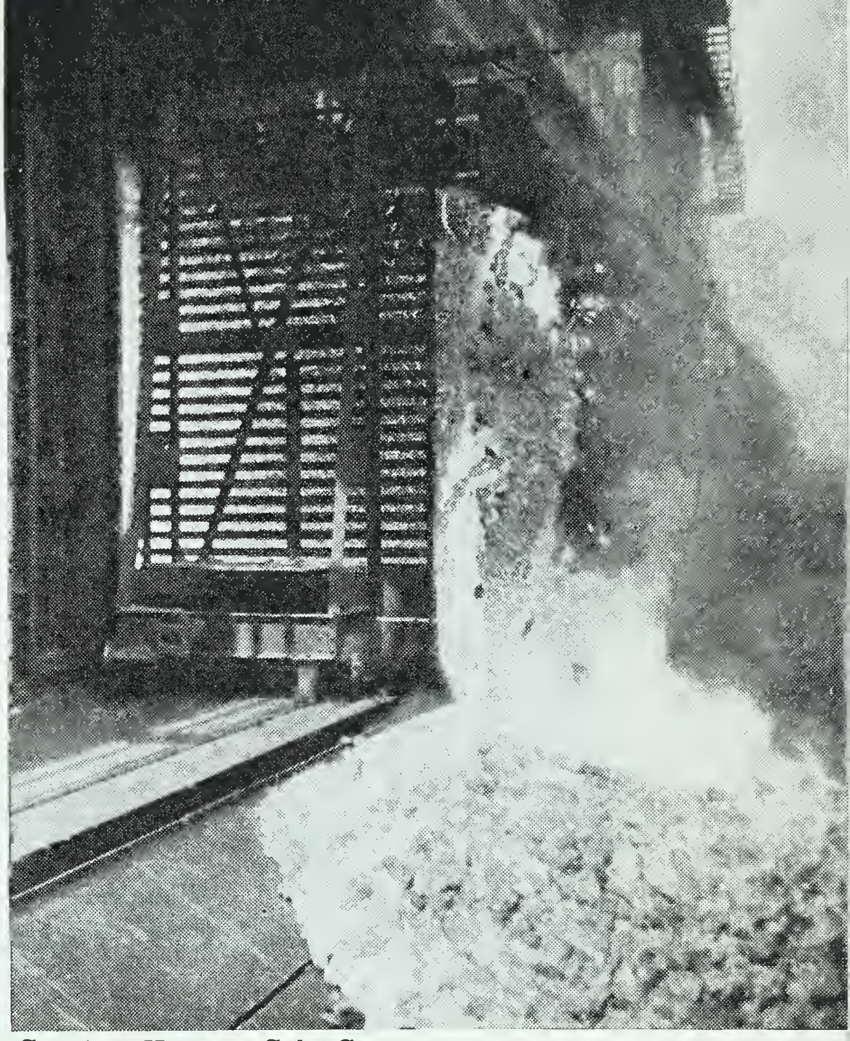
These Bavarian workers are sorting bricks of peat that have been dried in the sun. Canada and our own Atlantic Coast states have thousands of square miles of this "coal in the making."

Other varieties of coal include subbituminous coal, lignite, and peat. Even though these types of coal occur abundantly in various sections of the United States, none has assumed any great importance as a fuel. This is because they all possess undesirable properties and also because of our ample resources of anthracite and bituminous coal. Subbituminous coal and lignite "slack"—break into small pieces—on exposure to air. In addition, these fuels cannot be stored without danger of undergoing spontaneous combustion, and both have rather low heat values. Consequently, the area within which they can be transported and used with profit is restricted. Most peat as dug from bogs is about 90 per cent water by weight. It can be made into fuel by chopping, molding into bricks, and drying. Drying by exposure to air is slow; drying in ovens is expensive. Therefore, the use of peat for heating residences will probably not greatly increase in this country for many years to come. However, considerable quantities are used in some European countries, notably Ireland.

When bituminous coal is "baked" in a closed vessel from which air is excluded, gas and vapors are expelled and coke remains. Coke is a highly desirable solid fuel. It is clean, is smokeless, and leaves but little ash. It has a high heat value, and the fire is easily controlled if the correct method of firing is employed. Lack of information as to proper and effective methods of firing is the chief reason why coke has not been more generally used. In recent years, however, manufacturers and distributors of coke have done much to supply this needed information with the result that the use of this fuel is becoming more widespread.

The coke used in residence heating may come from several sources: (1) the retorts of coal-gas plants, as the residue remaining after the gas has been expelled from the coal; (2) by-product coke ovens, which are designed to produce coke and obtain gas and other

materials as by-products; (3) beehive coke ovens, which produce only coke. In the last-named method of manufacturing coke, the smoke, gas, and other vapors are allowed to escape into the air. Not only is this a very wasteful procedure, but it constitutes a distinct detriment to community health and cleanliness. Fortunately, the use of by-product coke ovens is rapidly increasing.



Courtesy Koppers Coke Company

A "push" of white-hot coke is tumbling from the oven into the quencher for cooling. What may become of this coke?

• LIQUID FUELS

Liquid fuels have many advantages over solid fuels. They are cleaner and more convenient to handle, less expensive to transport, and require smaller storage space which may be at some distance from the point of use. They give instant increase and decrease of heat and accurate control of temperature and burn with a hot flame which leaves no ash or residue. Care must be exercised in storage and handling because of the relatively greater hazards involved. For some uses solid fuels are less costly, and where cost is the only consideration, liquid fuels are not used.

Among the important liquid fuels are practically the entire range of petroleum products—gasoline, kerosene, distillate fuel oil, residual fuel oil, natural gasoline, and liquefied petroleum gases—and benzol, ethyl alcohol, and methyl alcohol. By far the greatest source of present-day liquid fuels is petroleum, in the form of both crude oil and natural gas.

The widespread use of petroleum products is a comparatively recent development, although early peoples knew of petroleum and used it to some extent for heating, lighting, and other purposes. In Pennsylvania and New York, oil coming from the earth gathers on the water of some springs and ponds; in colonial times it frequently was collected for use as a medicine. In the first half of the eighteen-hundreds, artesian-well drillers seeking salt brine



Courtesy A. O. Smith Corporation

Scorners called the first oil well "Drake's Folly" during the months of drilling when Drake encountered many difficulties.

in West Virginia and Pennsylvania often struck oil pools instead.

In the middle of the century, successful experiments had been made to distill oil for lamps from coal and shale, and a thriving industry was growing up manufacturing coal oil. At the same time, however, Samuel Kier, a Pittsburgh druggist, was trying to distill crude oil found as an impurity in his father's salt wells. In 1855 he was successful. Shortly afterward, in 1859, the American petroleum industry really was born when Colonel E. L. Drake drilled the first well especially dug to find oil. Almost overnight the infant coal-oil industry was forced out of business and replaced by petroleum refiners. Since that day the petroleum industry has become one of the world's greatest and most essential enterprises.

Petroleum is obtained by drilling wells. The first oil well was only 69½ feet deep, but now oil men drill through thousands of feet of earth and rock. The average depth of today's wells is about 3,000 feet, but many wells exceed one mile in depth, and there are twenty-five wells which have penetrated below 13,000 feet. The world's deepest man-made hole is a California oil well nearly three miles deep (15,004 feet).

Science today is trying to make certain that exploratory wells will find new oil fields, but as yet the drilling of a well in a new area is a high-cost gamble. Only one well in seven drilled with the utmost help of science finds oil in new territory; but only one in sixteen of those drilled without scientific advice strikes oil. Most wells drilled, of course, are additional wells which surround the discovery well of a new field, and only a very small part of these are the industry's failures, the "dry holes." This is fortunate, for a single deep well may cost $150,000 and more.

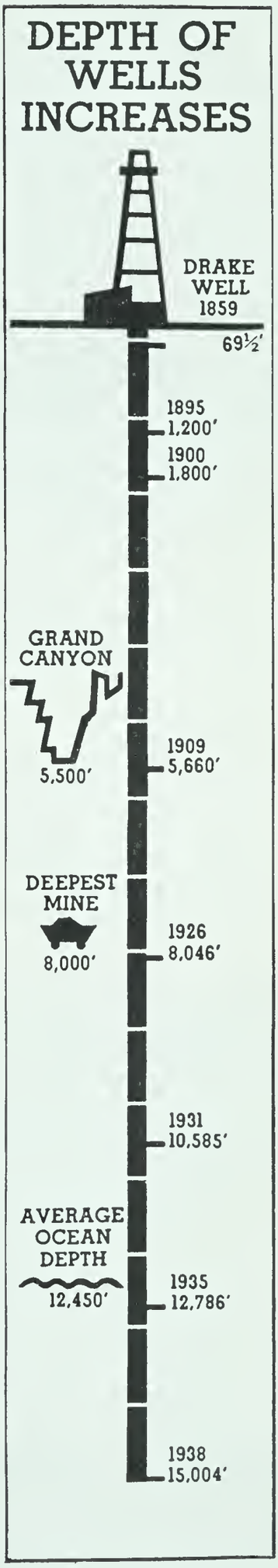
The typical oil sand (also called a pool or reservoir) is not an

open cavity in the earth in which oil has collected, but a porous sandstone or limestone formation which contains oil much as a sponge holds water. Impervious harder rock formations above and around the softer oil formation trap the oil and prevent it from escaping. The oil ordinarily is associated with natural gas and salt water, and either or both of these provide enough pressure so that many wells are self-flowing. Eventually the internal pressure subsides, and the remaining oil must be pumped to the surface. Some wells must be pumped from the beginning.

From the oil fields, which now are located in twenty-three states, the crude oil is transported to the refineries in thirty-five states by tankships and pipe lines. A small amount travels by tank car, tank truck, and barge. Much of the crude oil produced travels 1,000 to 1,800 miles to the refinery, for the greatest oil-producing area is the Southwest, and the important refining centers are in the Philadelphia-New York region, Chicago, St. Louis, the gulf coast of Texas and Louisiana, the Dallas-Fort Worth region, Tulsa, and along the California coast.

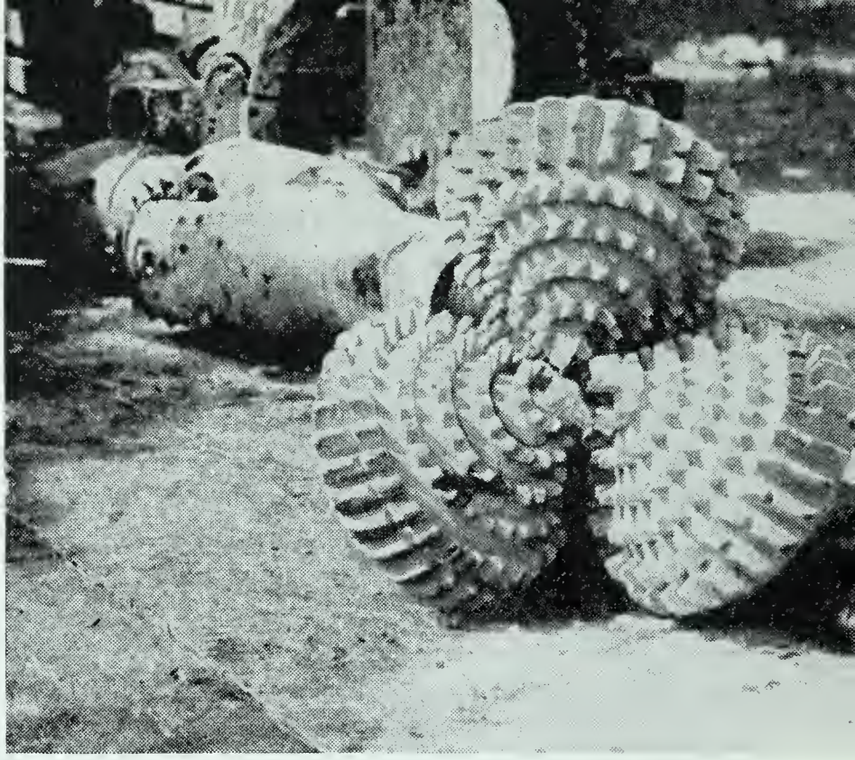
Petroleum refining fundamentally is simple. Crude petroleum is not a single substance, but is a mixture of hundreds of different kinds of molecules, called *hydrocarbons* because they are composed only of the chemical elements carbon and hydrogen. Groups of these hydrocarbons having similar properties, when separated from each other, make up the various refined petroleum products, in themselves mixtures. The various groups can be separated because they boil and vaporize at different temperatures.

Water boils at a single temperature; if the application of heat is continued, eventually



Courtesy American Petroleum Institute and The Pictograph Corporation

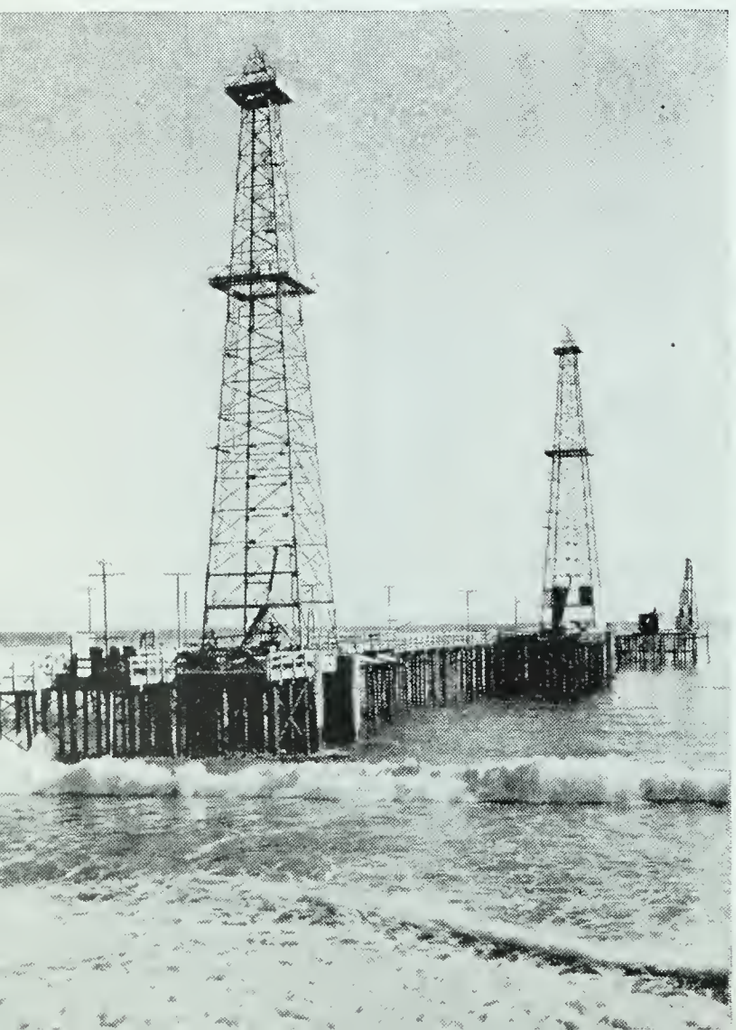




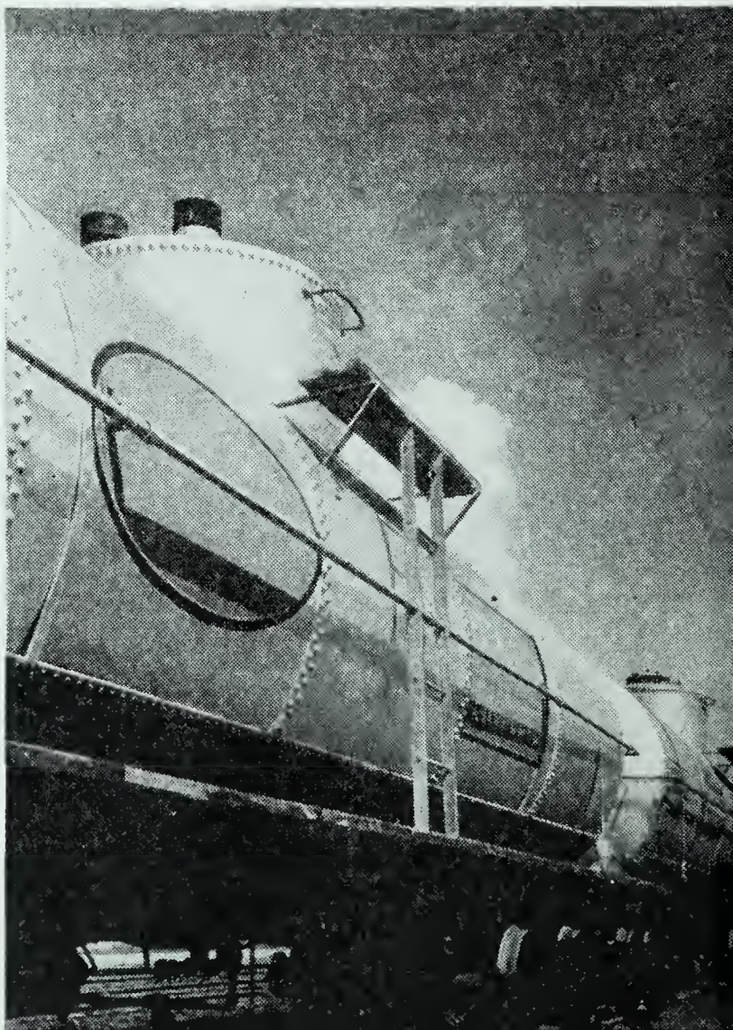
In its search for new oil fields, the petroleum industry makes use of seismology—earthquake science. A miniature earthquake is set up by a dynamite blast. Delicate instruments chart the route, speed, and direction of the vibrations within the earth, thus revealing the nature of the earth's formations. Formations favorable to oil are then tested with the drill. In the picture at the left, water and sand are seen rising from the dynamite blast. The charting instruments are within the truck. In drilling, huge bits like that shown at the right are used to penetrate hard, rocky formations. As it revolves the teeth grind through the formation, making the hole ever deeper.

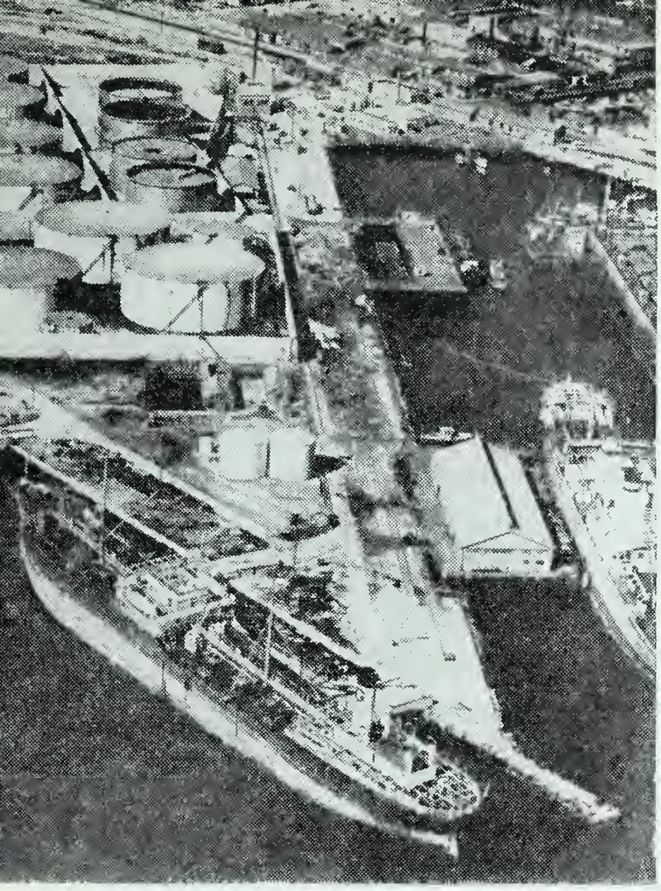
Photos courtesy American Petroleum Institute (top left and right and bottom right); The Inman Company (bottom left)

The sea is no barrier to the petroleum engineer. If there is oil beneath the sea, he goes after it.



Tank cars like the one shown below hold 6,000 to 10,000 gallons of gasoline each.





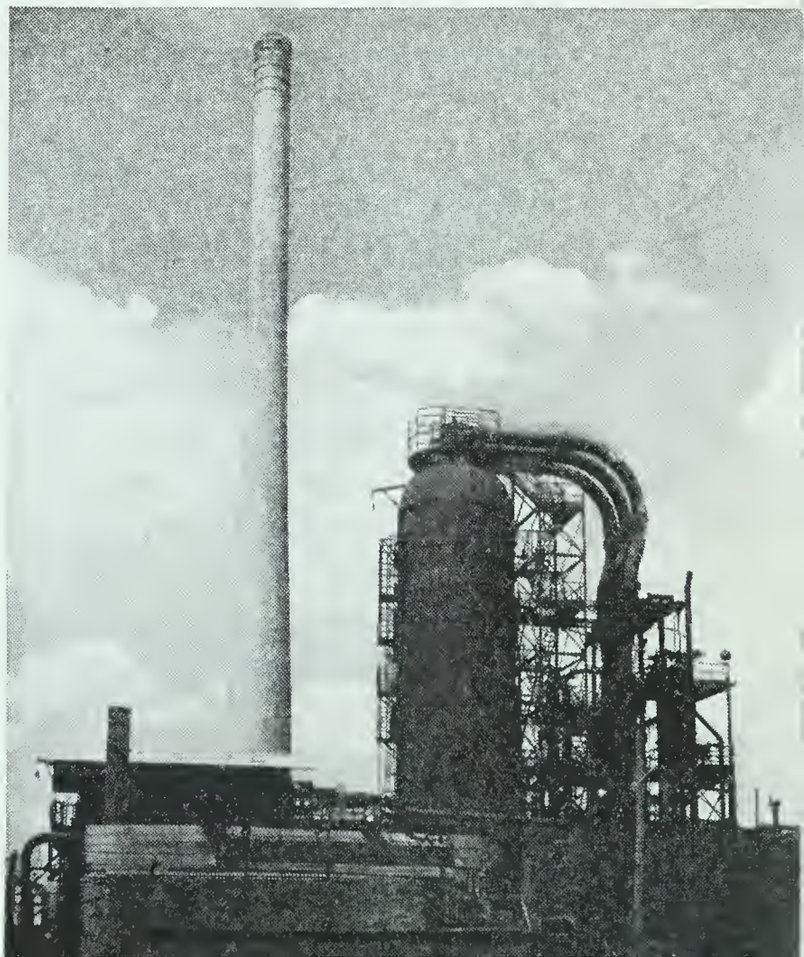
A fleet of tank ships transports petroleum and its products to markets in the United States. The photo shows a modern loading dock.



Tankers discharge their cargo of petroleum through metal-reinforced hoses which are dropped deep into their holds.

all the water will vaporize. Contact with a cooler temperature causes the water vapor to condense and liquefy again. Almost exactly the same procedure is the basis of the simplest petroleum-refining method, straight distillation. Crude petroleum is heated in a still at progressively greater temperatures. Up to a certain temperature, everything that vaporizes and is then condensed into a liquid is one product; between that temperature and the next higher level, another product boils out.

The lighter groups of hydrocarbons—those boiling at the lowest temperatures—are naphthas and gasolines, followed by kerosene, light fuel oil, and



This is a modern still for refining petroleum. Here scientific principles and the results of experimentation are applied to the production of gas, gasoline, refined oil, and lubricating oil.

Photos courtesy Socony-Vacuum Oil Company, Inc., Spence Air (top left); American Petroleum Institute (top right and bottom)

other products. Heavy fuel oils, asphalts, waxes, and some lubricants do not vaporize at the temperatures ordinarily used in refining. They remain in the still and are drawn off and separated by other means. After the crude petroleum has been distilled, there remains in the still a black, tarry residue. Even this is used. From it can be obtained pitch and asphalt, for use in roofing and road-building, and petroleum coke, for use as a solid fuel.

Modern refining methods have advanced far from this simple procedure, but it still is the basic principle. Straight distillation itself has been improved tremendously, particularly through the introduction of new techniques which make it possible to get more exact fractions and to operate continuously twenty-four hours a day the year around. Some of the largest refineries process every day more than five million gallons of crude oil.

The most notable recent advances in refining technology have been in the introduction of chemical-refining methods. Straight distillation essentially is physical separation. In chemical refining, hydrocarbon molecules, instead of merely being separated into groups, actually are forced to change from molecules of one type to molecules of other types. The heavier molecules, such as those in the fuel-oil group, can be torn apart to make lighter molecules to mix with the other light molecules as gasoline. Hence a given quantity of crude petroleum can be made to yield much more gasoline and less fuel oil.

The first major process to accomplish this chemical conversion of petroleum hydrocarbons was *thermal cracking,* introduced in 1913. This process involves the use of great heat while the oil is under pressure. Cracking alone has more than doubled the amount of gasoline that can be made from a given quantity of crude petroleum, and since 1920 has conserved more than eleven billion barrels. Since 1930, however, chemical refining has advanced tremendously with the development of such processes as hydrogenation, polymerization, and catalytic cracking, to mention only a few. In *catalytic cracking,* the oil is vaporized and the vapors are subjected to the effect of a specially prepared chemical agent, the catalyst, which breaks down the large molecules and rearranges them to form gasoline.

With the introduction of cracking, a major by-product of petroleum refining became refinery gases. For many years these waste gases were used almost solely as boiler fuel at refineries, but the introduction of polymerization has made them much more valuable. *Polymerization* is the reverse of cracking. The hydrocarbon

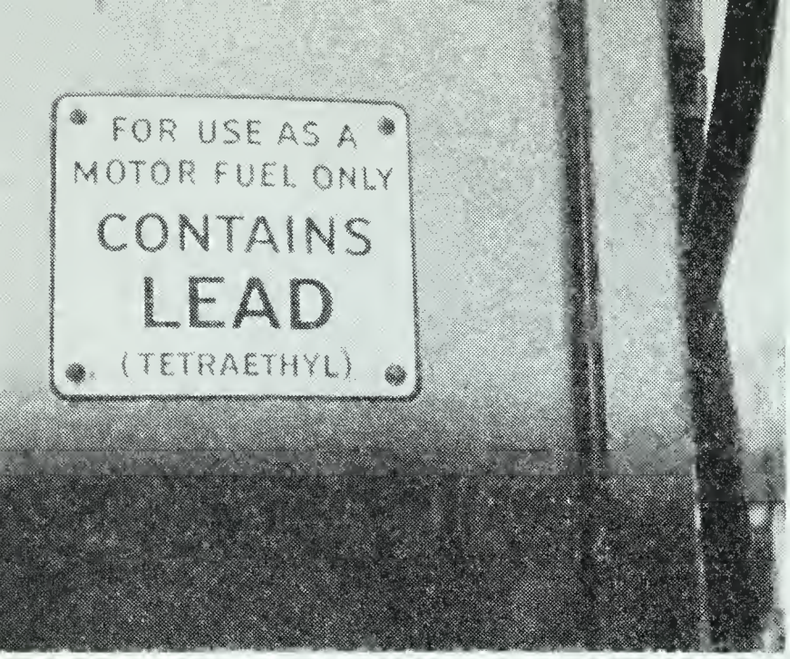
molecules in the refinery gases are too light, but through polymerization they are combined to make new gasoline molecules. The product is sometimes known as "poly" gasoline, which you may have seen advertised. One important contribution of many of the new refining methods has been that the type of crude oil used is increasingly less important. The new methods make it possible to manufacture the products desired from nearly any type of crude oil.

Besides increasing the yield of gasoline, these chemical refining methods have improved materially the quality of gasoline, particularly in its antiknock characteristics. Many of the new techniques, in fact, have been introduced to make possible the manufacture of the super aviation motor fuels of which the United States fortunately has almost a world monopoly. Chemical synthesis—that is, building up complex products from simpler ones—also has resulted in the use of petroleum as the source of dozens of industrial chemicals, and petroleum has become the base of hundreds of products. Most important now are the newer ones, the synthetic rubbers, toluol, and glycerin. Beyond them are the older industrial alcohols, paints, solvents, resins, plastics, and scores of other products.

Gasoline is also produced directly from natural gas by several methods. This natural gasoline, or *casinghead* gasoline as it once was called, evaporates extremely rapidly. Ordinarily it is not used alone as a motor fuel but is blended with refinery gasolines to control volatility, an important characteristic in today's automobile engines. On the average, 1,000 cubic feet of natural gas yield 1 gallon of natural gasoline; production totals more than two billion gallons, or about 8 per cent of total motor-fuel production in the United States.

Gasoline for years has been the major petroleum product. Production by all methods now reaches the tremendous total of about twenty-six billion gallons a year. In 1940 almost twenty-five billion gallons were consumed in the United States, of which about twenty-two billion gallons, or about 89 per cent, were used by motor vehicles. The remainder was consumed on farms, principally by tractors; in building and road construction; in airplanes and motor boats; in manufacturing; in dry cleaning; and in many other ways.

Many qualities of motor fuel are important to its successful use in automobile engines. Volatility, gum content, sulfur content, distillation range, tendency to corrode, vapor pressure, and many



This familiar sign is seen on most gasoline pumps.

other factors are carefully controlled by petroleum refiners. The one quality which has received the most popular attention is the so-called *octane number,* or antiknock characteristic. Importance of this quality lies in the introduction by the automobile industry of motors with continually higher compression ratios, which demand increasingly precise fuel explosions in the engine cylinders.

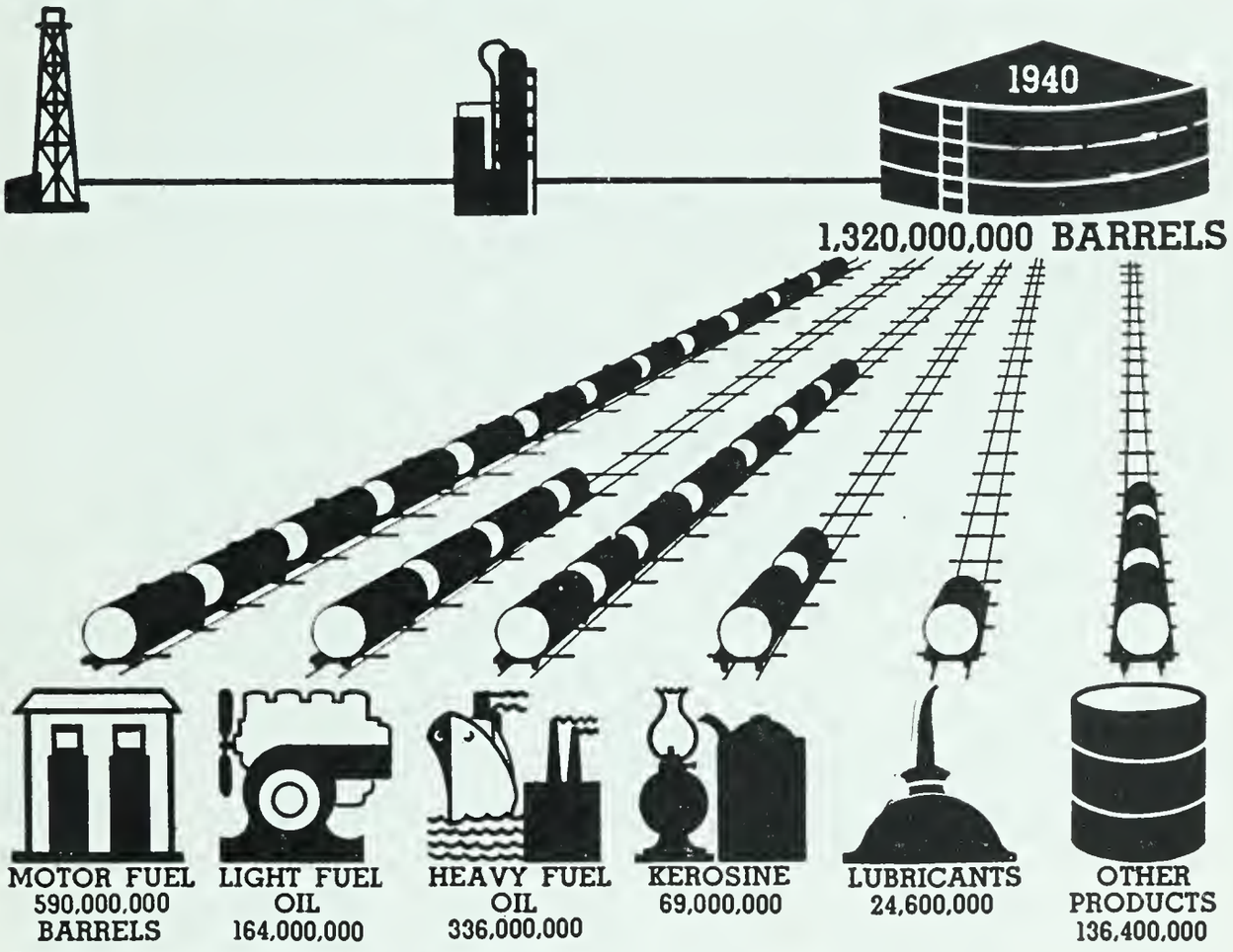
The term "octane number" came into use because in the early days of experimenting with this characteristic of motor fuels, a pure octane or iso-octane was rated at 100 per cent, and fuels were tested against standard laboratory mixtures of iso-octane, a hydrocarbon which will hardly knock at all, and heptane, a petroleum fuel which knocks violently. A fuel rated at 75 octane performed in the laboratory just like a test fuel which was 75 per cent iso-octane and 25 per cent heptane. Average octane numbers of motor fuel have increased rapidly so that the regular grade of motor fuel now bought by motorists throughout the country averages 74, or better than premium fuels of 1931.

Improvement of the antiknock quality in many brands of gasoline is brought about by the use of small quantities of tetraethyl lead, which helps regulate the rate at which the gasoline burns in the cylinder. Inasmuch as tetraethyl lead is poisonous, ethyl gasoline should not be handled directly by a person. In other words, ethyl gasoline should be used only as a motor fuel; many states have laws which are intended to prevent any other use.

Petroleum research has progressed so far, however, and refining techniques have advanced so rapidly that the petroleum industry now turns out vast quantities of 100-octane motor fuel for airplanes, and in the laboratory actually has made experimental fuels equivalent to 125 octane and higher. As recently as 1934, 100-octane fuel was a laboratory curiosity costing $30 a gallon.

Octane number is determined by a number of different testing methods, both in the laboratory and in actual road performance. It has become more clear recently that there are marked differences in the results of the various tests on the same fuel. Research engineers have called attention to the fact that octane number is not a

HOW PETROLEUM IS USED IN THE U. S.



Courtesy American Petroleum Institute; The Pictograph Corporation

In the twenty years since 1919, the consumption of petroleum products in the United States has more than tripled. "Other products" from petroleum, relatively small in volume, are becoming more important. Alcohols, glycerin, synthetic rubber, plastics, cosmetics, medicines, explosives, paints, dyes, and textiles are only a few of the hundreds of essentials that today are being made partly or wholly from petroleum.

completely reliable index of the ability of a fuel to prevent knocking.

Other petroleum fuels are used mostly for heating. Gasoline is by far the most important petroleum fuel used in transportation, but there has been some increasing use of other petroleum fuels for this purpose. Diesel engines are becoming more numerous in some applications. It is probable that Diesel-powered passenger cars will not be used much, if ever, but many new Diesel trucks and busses appear on the highways every year. The number of Diesel-powered trains, tractors, power plants, and vessels is growing steadily, as will be discussed in the study of man's adjustment to power in the next unit.

Use of another petroluem fuel, liquefied petroleum gas, in heavy

trucks on the Pacific coast is growing, but the total still is negligible. Kerosene for many years has been used as a tractor fuel, but this use is believed declining with the introduction of high-compression tractor motors operating economically on gasoline.

Light and heavy fuel oils also are used for power in transportation and in railroad locomotives and ocean vessels, but in these applications they are a substitute for coal and are burned under boilers to raise steam.

The burning of fuel oils for actual space-heating is, however, their most important use, and it has been increasing rapidly since 1925. More than two million homes in the United States now are heated by oil burners in central-heating plants, and possibly two millon more are partly or entirely heated by room heaters and space heaters burning kerosene or light fuel oil.

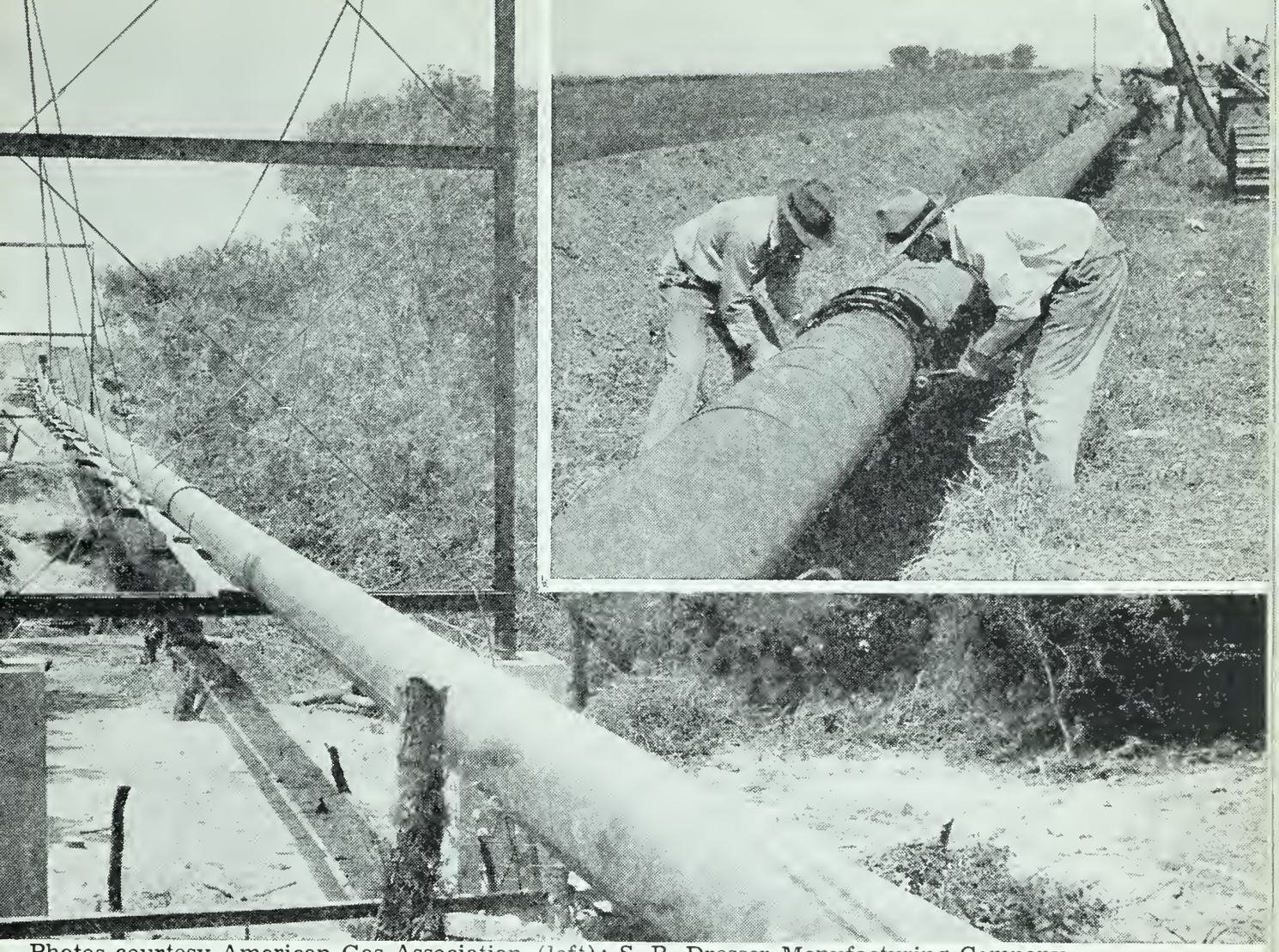
Light heating-oil specifications are governed by standards of the National Bureau of Standards, which designates Nos. 1, 2, and 3 for heating. No. 1 fuel corresponds roughly to kerosene and is sold for room heaters, cooking stoves, water heaters, and some heating-plant oil burners. In some sections of the country it often is called "range oil." Nos. 2 and 3 do not differ greatly and are used almost entirely for domestic oil burners. The No. 2 heating oil is almost identical with some Diesel oils, and occasionally is used as Diesel oil. It also corresponds roughly with so-called "gas oil," which is used by the manufactured-gas industry as a gas enricher.

The heavy fuel oils, Nos. 5 and 6 in the Bureau's specifications, are called residual fuel oil or bunker oil, the latter from their use as ships' fuel, one of the most important applications. Other important uses are in industrial plants and for apartment-house and large-building heating.

One gallon of fuel oil on burning yields from 136,000 to 141,000 B.T.U.'s, or roughly ten to twelve times as much heat as one pound of coal, assuming both are burned at 100 per cent efficiency.

• GASEOUS FUELS

Gaseous fuels possess the advantages of easy control, cleanliness, convenience, and immediate increase or decrease of heat as desired. In addition, they have the advantage, at least in cities, of being piped directly into the building, thus making individual storage tanks unnecessary. About the only drawback to the use of gas is the fact that in many localities it costs more than other common fuels.



Photos courtesy American Gas Association (left); S. R. Dresser Manufacturing Company (insert)

Pipes transport gas. To make them tight the lengths of pipes are either welded together or joined by couplings.

For residential purposes in urban centers, natural gas or "artificial gas" manufactured from coal may be used. So-called "tanked gas" or "bottled gas" is available for use in rural localities. The gas is supplied in a highly compressed, liquid condition in strong steel cylinders, which are attached to the gas lines of the building. The containers can easily be refilled or replaced by new ones when necessary. Gases supplied in this way include propane and butane, two gases obtained in the refining of petroleum.

Natural gas occurs in association with petroleum. These underground storehouses of compressed fuel gas are tapped by drilling into the crust of the earth. An iron casing pipe is driven into the rock formation which always lies above the gas-bearing sand. A special plugging device is fastened in the casing just above the gas formation, and the gas, because of its inherent tendency to expand, rises through tubing to the surface. This same expansive force causes it to flow through transmission lines to the consumer. As the gas flows, its pressure drops, necessitating the installation of compressors at various intervals. Their function is to recompress the gas, so that it will continue to flow through the trans-



Courtesy Chicago Bridge and Iron Company

"Hortonspheres" for storing gas under pressure are much different from the large, cylindrical tanks in which gas is stored over water.

mission lines. When the gas reaches a distribution plant, it passes into medium-pressure lines in the city, and thence into low-pressure mains. A pipe, called a service line, connects with the street main at the curb and with the house lines of the consumer at the meter.

The rise of the manufactured gas industry is a fascinating story. About 1660, Dr. John Clayton, an English clergyman, discovered that when a certain kind of coal was heated in a closed vessel, a "spirit which issued out caught fire at the flame of a candle." He delighted himself and amused his friends by collecting small quantities of the coal gas in bladders which he would prick with a pin, afterwards lighting the colorless gas with a candle. In 1792, William Murdock, a construction engineer for James Watt, lighted his home by coal gas, and in 1804 he built a gas works to light a large cotton mill with 900 burners.

The manufacture of coal gas spread to other countries, including the United States. Baltimore was the first city over here to light its streets with gas; this took place in 1816. During the years 1865 to 1875, home lighting by gas first began to make rapid strides. It was about 1895 before gas was first used to any considerable extent as a fuel for domestic cooking. Today, 1,500,000 gas stoves are sold each year in the United States alone. In addition, enormous quantities of gas are now being used for heating purposes.

In the manufacture of coal gas, bituminous coal is heated in big retorts of iron, clay, or brick. The coal is put into the retorts, which are then sealed to keep out the air. When the coal is heated sufficiently, it tends to fuse, meanwhile giving off gas and other vapors. Afterward, all that remains in the retort is coke.

Upon leaving the retort, the gas passes into the collecting main where the condensable vapors deposit. The deposit is chiefly coal tar, a thick, sticky, vile-smelling material, the disposal of which formerly constituted a difficult problem. It was often emptied into the rivers, where it killed the fish and vegetation and spoiled the appearance of the stream. Coal tar is today one of the most useful



Courtesy Consolidated Edison Company of New York, Inc.

These are gas mains under what is normally a busy city street.

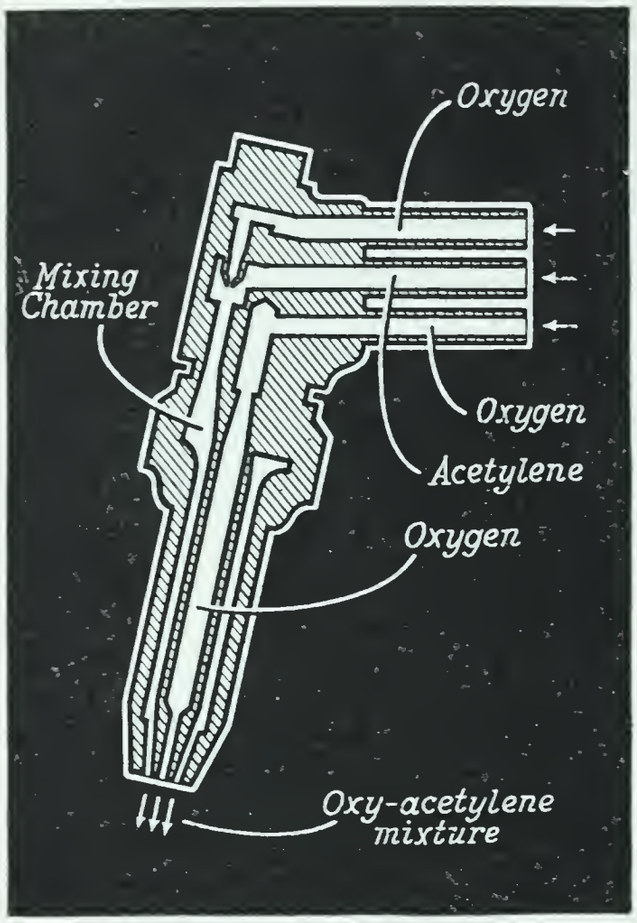
by-products of the coke oven. The number of valuable materials manufactured from it is exceedingly large and varied, including medicines and drugs; explosives; dyes with colors more varied than those of the rainbow; saccharin, a substance five hundred times sweeter than sugar; perfumes whose shades of odor outdo those of nature; flavoring agents; naphthalene, an insecticide familiar as moth balls or flakes; and various liquids which serve as solvents and fuels.

Ammonia, some tar, and a few other objectionable impurities still remain in the gas. These are removed by passing the gas through specially designed compartments containing purifying materials. The coal gas is at last ready for consumption. It passes through a large plant meter, which measures the quantity manufactured, and thence to a storage holder. From the gas holder it flows through a vast network of mains and service pipes to thousands of consumers.

At the present time, about 75 per cent of the cities in the United States use carbureted water gas. To generate this gas, a cylindrical vessel lined with firebrick is filled with coke or anthracite coal which is ignited. A blast of air is blown through the apparatus until the fuel becomes white-hot. At this time, the supply of air is turned off, and steam is sent into the generator. The steam reacts chemically with the hot carbon to produce a mixture of two combustible gases—carbon monoxide and hydrogen:

$$\underset{H_2O}{\text{water}} + \underset{C}{\text{carbon (coke)}} \longrightarrow \underset{CO}{\text{carbon monoxide}} + \underset{H_2}{\text{hydrogen}}$$

The mixture of these two gases is known as "blue" water gas.



What hypothesis would you suggest to explain why the oxyacetylene mixture burns at the tip of the burner and not in the mixing chamber?

This is sometimes used as a commercial source of hydrogen and carbon monoxide.

To increase the heating value of blue water gas, it is "enriched" by mixing with it gases of high heating value derived from oil. In addition, this procedure makes it possible to burn the gas with a luminous flame. It also imparts a distinct odor, which is desirable, since carbon monoxide is poisonous and neither it nor the hydrogen has an odor. To enrich the gas, a certain kind of oil obtained from petroleum is sprayed in at the top of the carburetor while the water gas is flowing through. The carburetor is really a compartment containing a honeycomb of brick which is kept hot. As the oil comes into contact with the hot bricks, it is chemically "cracked" into gases of high heating value. The gases from the oil and those from the generator mix and are ready to be purified and distributed.

After the steam passes through the white-hot carbon in the generator for a certain time, the temperature drops to the point where the desired reaction no longer takes place. It is then necessary to shut off the steam and force a blast of air through the coke or anthracite until it again becomes white-hot, after which the process is repeated. After purification the gas is measured and stored in large holders from which it is pumped to consumers.

Producer gas and acetylene are manufactured in significant quantities, primarily for use as industrial fuels. Producer gas is prepared from low grades of coal and is therefore a cheap fuel. For this reason, it is extensively used in spite of its low heating value. The method of manufacture closely resembles that used for water gas. A regulated supply of air is forced through a thick layer of incandescent coal in a suitable container. The amount of

air is insufficient to permit complete combustion; therefore, considerable carbon monoxide is formed. This is the combustible constituent of producer gas. When prepared in this manner, producer gas contains about 60 per cent nitrogen, but sometimes steam is also forced in with the air blast, causing the gas to contain some hydrogen. Blast furnaces, such as those used in extracting iron from iron ore, give off producer gas as a by-product; it is generally burned to provide some of the heat necessary for the operation of the furnace. Manufactured producer gas is used to fire large industrial furnaces, such as those used in manufacturing steel and glass.

The chief use of acetylene at the present time is for the production of extremely high temperatures. When burned in an oxyacetylene torch, temperatures in the neighborhood of 3000° centigrade can be obtained. Such temperatures are useful in cutting metal plates and beams, in wrecking steel structures, and in welding metals.

Acetylene is produced when water reacts with a chemical called calcium carbide, which is made from coke and limestone in an electric furnace. The acetylene reaction usually takes place in a specially designed apparatus arranged to generate the gas as needed and to prevent air from mixing with it. Air and acetylene form dangerously explosive mixtures. Acetylene is often stored and transported in strong steel cylinders. These cylinders contain fibrous asbestos saturated with a liquid called acetone, in which the acetylene is dissolved under pressure. If acetylene is compressed alone in the cylinders, it is highly explosive.

• FUELS AND THE FUTURE

There is much talk about conservation these days, and occasionally we read accounts of estimates as to how long our reserves of coal and oil will last. Some of these give us quite a scare, and we begin to imagine the dire consequences of exhaustion. Let us see what the known facts are with respect to this situation.

We all know, of course, that our coal and oil must certainly some day become exhausted. Just when this will occur is quite uncertain, but the time seems much more remote for coal than for oil. According to the National Resources Committee, coal beds known at the present time, and which can be mined under present conditions, provide reserves sufficient to last at least an estimated two to four thousand years. Probably not more than 1 per cent



Courtesy Linde Air Products Company

The hottest flame man has produced. It slices through steel like a band saw cuts through wood. Straight lines, circles, or jigsaw-puzzle pieces are produced if desired—in steel a foot or more thick.

of the original supply of bituminous coal and about 25 per cent of our anthracite coal have been exhausted. It should be remembered, however, that the best coal from the most favorably situated beds is mined first. About one-half of our total coal reserves consists of subbituminous coal and lignite, both of which are inferior fuels and are located in the western part of our country far from present population centers.

On the other hand, the reserve life of oil apparently will be shorter. An independent petroleum engineer recently conducted a survey for the benefit of certain oil-producing states. On the basis of his report, it is evident that large, additional oil reserves will have to be located; otherwise, we may be running short of petroleum before twenty years have passed. And, we ask, "What then?" At the present time, several possible solutions to the problem seem likely to occur: (1) the discovery and development of new oil reserves, although the rate of discovery is decreasing rapidly and costs of development are rising; (2) the reworking of older, abandoned wells, many of which yield considerable quantities of oil when worked by new and better methods—such as mining and the use of water pressure; (3) the utilization of shale oil, that is, oil obtained by distilling certain kinds of shale rock which occur abundantly in our western states; (4) the importation of oil from other countries; (5) the production of alcohols for fuels, chiefly by the fermentation of sugar; and (6) the manufacture of gasoline from coal.

In the production of gasoline from coal, soft coal is pulverized, mixed with oil, and heated with hydrogen under special conditions. The United States Bureau of Mines has recently announced that it is now possible by means of this process to convert coal directly into a product resembling crude oil, kerosene, gasoline, or any other petroleum product. The process is now used to a



Courtesy U. S. Bureau of Mines

Not only rock but oil, too! Oil-shale hills in western United States may supply us with petroleum products when present resources are exhausted.

considerable extent in Germany, England, France, and Japan. Ingenious as it is, however, it is a wasteful method of obtaining power from coal. About four tons of coal are required to manufacture one ton of gasoline by this method, and the resulting gasoline contains only 40 to 45 per cent as much energy as the coal used. It is desirable, therefore, in the interests of conservation to delay as long as possible the day when we must manufacture our gasoline from coal. One method of achieving this end would be to stop using oil in direct competition with coal. One could certainly question the wisdom of using oil as a domestic heating fuel when we well know that when the oil is depleted a substitute will have to be made from coal.

All these possibilities suggest a much higher price for gasoline, but they indicate, too, that at worst, the depletion of our oil resources will not be a national catastrophe. Nevertheless, people today generally recognize the need for conservation, and it should be looked upon as an adjustment problem to be shared by producer, consumer, and governmental agencies. Many states have already put into effect legislation regulating the production of petroleum. Oil produced in violation of such laws is known as "hot oil." The federal government is interested in the problem and is devoting much attention to related research and the accumulation of reliable data by means of various bureaus, experiment stations, and fact-finding committees. In view of the valuable by-products that can be obtained by the coking of coal, it is wasteful and extravagant to burn soft coal directly as a fuel; nevertheless, at the present time, less than 10 per cent of the soft coal mined in this country is coked. Likewise, it is wasteful and expensive to burn gas in furnaces and other heating systems not designed or adapted for the use of this fuel; some authorities have even suggested that this practice be prohibited by law in the interest of conservation.

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Exercises for Problem Study and Review

1. Why does the water content of wood decrease the amount of heat obtained by burning it?
2. What are by-products? What are some by-products that can be obtained in the manufacture of charcoal?
3. Why is anthracite coal generally preferred to bituminous coal for home heating?
4. How is coke manufactured? Compare it with anthracite and bituminous coal as a fuel for heating homes.
5. What kinds of solid fuels do railroads and large industries use? Why?
6. What advantages have liquid fuels over solid ones? Name five common liquid fuels.
7. Under what conditions is petroleum usually found? Describe how it is obtained from the ground. How is it transported?
8. How is the mixture of hydrocarbons found in petroleum separated into kerosene, gasoline, naphtha, vaseline, paraffin, lubricating oil, etc.?
9. How is gasoline made from petroleum?
10. What advantages does ethyl gas have over "white" gasoline? Why is it more hazardous to use ethyl gasoline than regular gasoline for cleaning clothing? Should either kind be used for this purpose?
11. What is meant by the "octane rating" of a gasoline?
12. What is the significance of numbers when applied to fuel oils?
13. Give several reasons why gas is the ideal fuel. Why is it not more widely used?
14. What is "bottled" gas? How is it made? How is it used?
15. Describe how natural gas is obtained and distributed.
16. How is coal gas made? How is it stored and distributed?
17. What is coal tar? Why is it no longer discarded as worthless?
18. How is carbureted water gas made? What gases does it contain? Why must it be used with care?
19. How is producer gas made? Why is its use limited?
20. What are the important uses for acetylene? How is it stored?
21. Give examples wherein we have failed to conserve (1) a gaseous fuel; (2) a liquid fuel; (3) a solid fuel.
22. How can gasoline be made from coal? Why is this process already proving to be a valuable discovery for certain nations? Why is it likely to become increasingly valuable to other nations?
23. What is the outlook for the future with respect to our reserves of coal and petroleum? What are some possible ways of meeting a depleted oil supply?
24. What petroleum products are commonly used in and around the home?
25. Which are the chief chemical elements that comprise fuels?

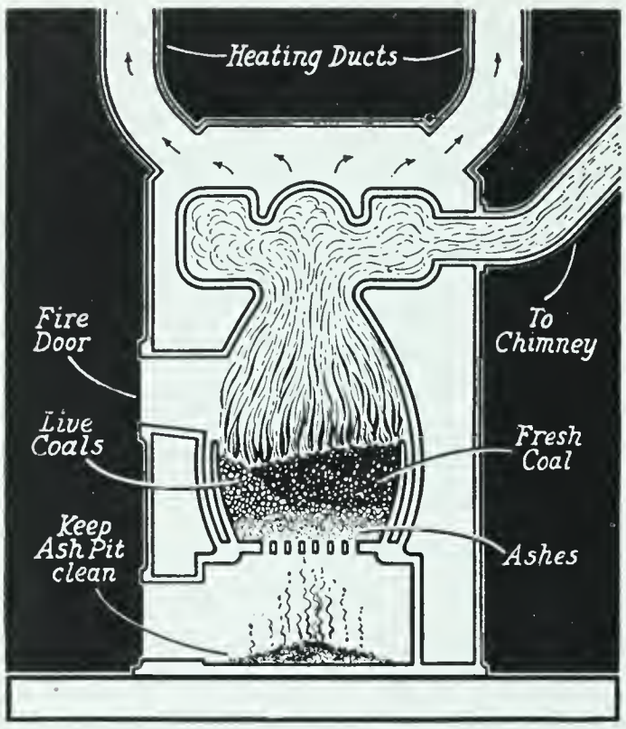
Problem 3: How does man control fire and burning?

• DEVICES FOR CONTROLLED BURNING OF FUELS

Our study of the nature of burning makes it evident that proper regulation of the air supply is of vital importance in the economical use of any fuel. Benjamin Franklin's iron "stove," invented in 1742, paved the way for the development of those in use today. The increased efficiency of the stove over the fireplace was caused partly by better regulation of the air supply and partly by the fact that it confined and conserved the liberated heat more effectively. Dampers in the smoke pipe and draft slides in the fire and ashpan doors made better control possible. Furnaces used in present-day central-heating plants employ similar controls. In this country such centralized plants have largely displaced individual stoves located in various rooms.

Faulty combustion of the fuel adds unnecessarily to the cost of heat production, no matter what fuel is used. Admission of too little air to the fire wastes fuel because of incomplete combustion and in addition pollutes the outside air with unburned fuel in the form of smoke and poisonous gases. On the other hand, excessive amounts of air have an expensive cooling effect. While it is true that burners vary in efficiency, the fact remains that lack of skill in firing and in adjusting the regulatory devices is one of the most common causes of unsatisfactory results. It is, of course, desirable that the amount of attention required by the burner, as well as the operating expense, be held to a minimum while maintaining the desired rate of heat production. The choice of a fuel and the selection of the burner are often made on the basis of one or the other of these two items.

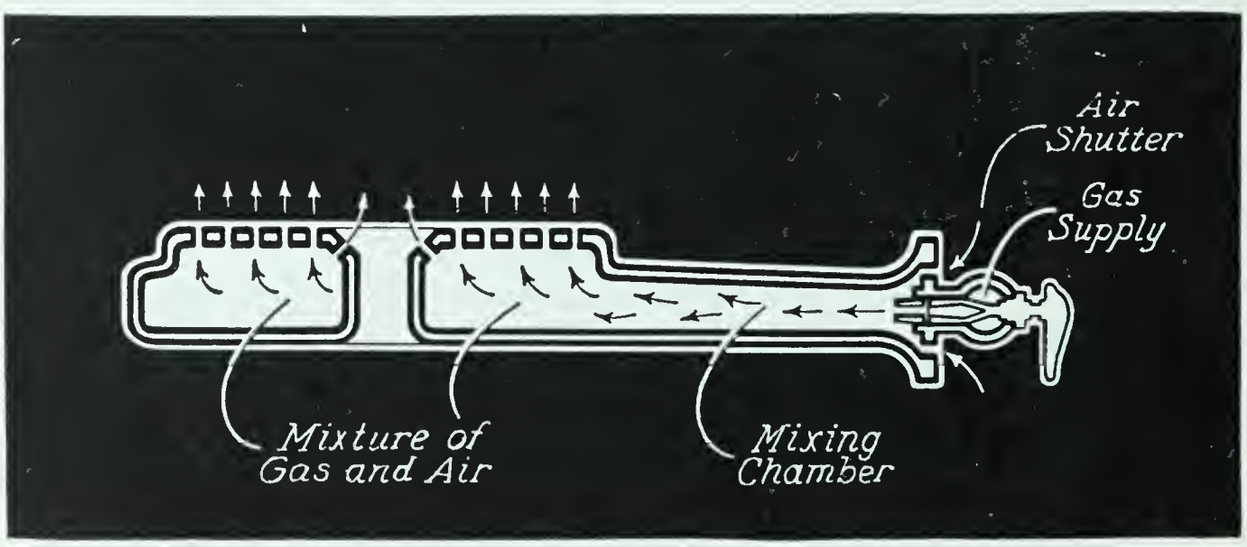
The problem of selecting the most satisfactory method of firing for any given set of conditions involves necessarily the consideration of two factors: (1) the type of burner; and (2) the kind of fuel. When coal or coke is burned, the size of the air passages in the grate determines the size of fuel used. Solid fuel is generally easier to burn efficiently in residence heating if it is fairly uniform in size. The small sizes tend to pack on the grate, and, unless the chimney draft is very strong, they require a blower to force air through the fire bed to speed up the rate of burning. On the other hand, the larger sizes of fuel are more expensive but require no forced draft. Whether or not a blower is used on



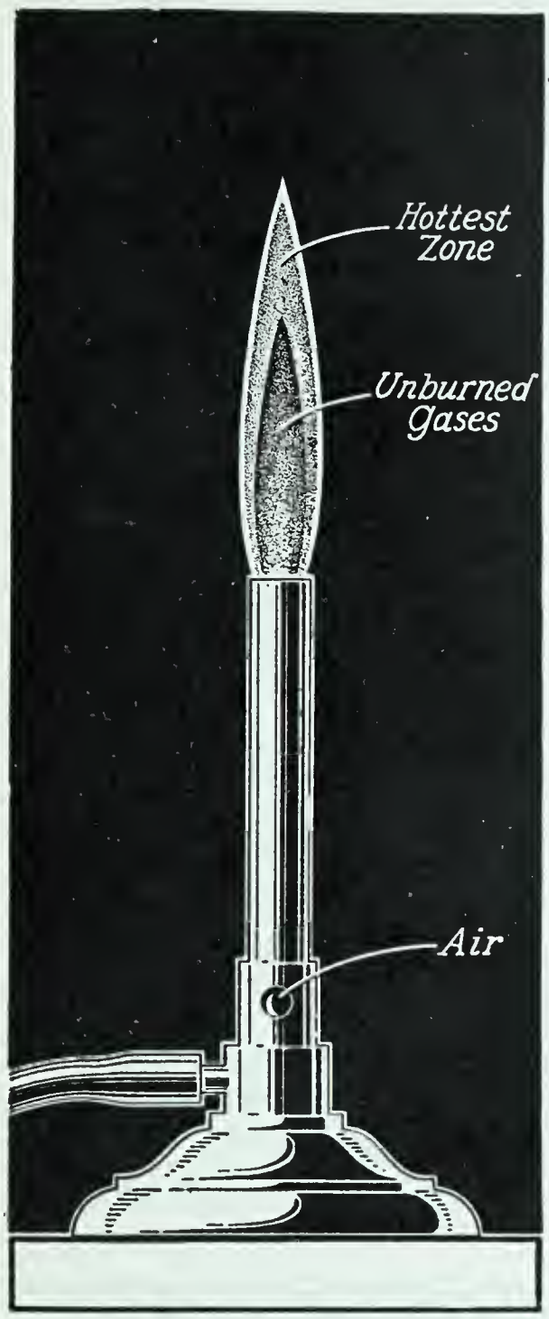
In the coking method of firing, the live coals are not entirely covered with fresh fuel.

a coal fire, an area of uncovered, glowing fuel should be left after each firing to ignite combustible gases which might otherwise collect and form an explosive mixture. Since slight explosions sometimes occur in the furnace after bituminous coal has been added, the firing door of this type of furnace should have a lift damper to relieve automatically the pressure at such time and to prevent the furnace door from being blown open. Manufacturers provide specific directions for operating each type of burner sold; fuel companies often provide complete inspection service and give suggestions for increasing the efficiency of the heating system examined.

Methods of firing vary with the type of fuel used. Anthracite coal requires a thick fuel bed so that a large excess of air is not admitted by the fuel burning through in spots. Coke is very porous and hence less dense than anthracite coal. Consequently, a greater volume of coke than of anthracite is required at each firing if the fire is to last as long in each case without attention. Bituminous coal requires more air immediately after firing than



The Bunsen principle is applied in the gas burner and the oil burner.



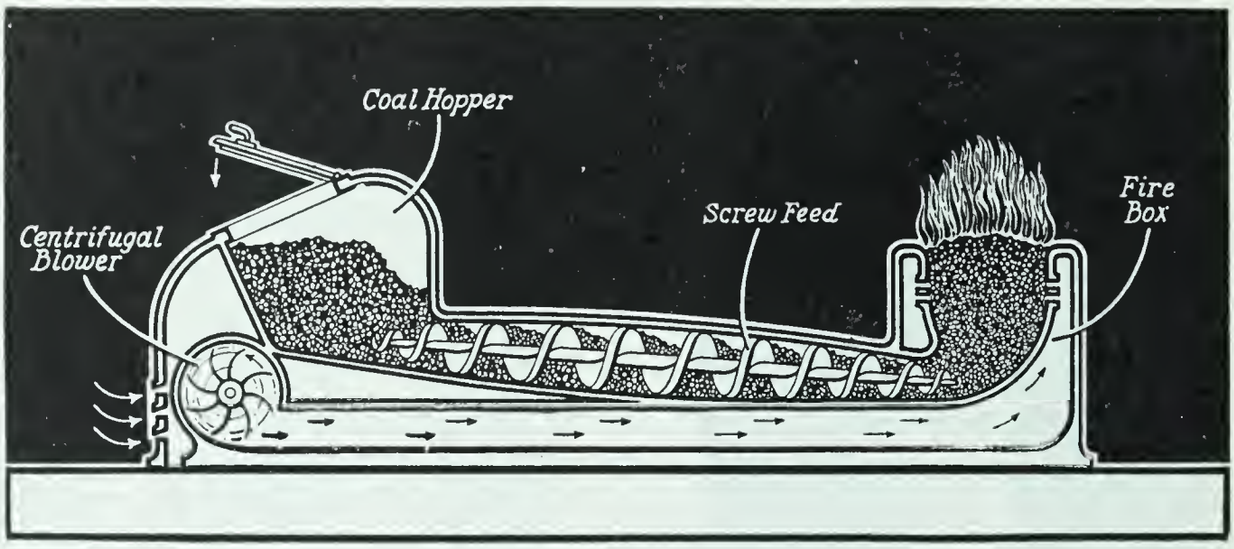
What are the characteristics of a properly adjusted Bunsen flame?

either anthracite or coke. Best for bituminous coal is a coking method of firing in which the fire is not entirely covered with fresh fuel. Covering all of the burning surface cools the firebox below the kindling temperature of the combustible gases leaving the coal, and they pass up the chimney unburned. This waste is eliminated by gathering to one side of the firebox the partly burned fuel, which has been changed into coke, and then adding the fresh fuel to the vacated area. When banking this kind of fire to make it last overnight, leave the drafts open for half an hour or so after adding the heavy charge of fuel. Some of the volatile content of the coal is thus driven off before the air supply is decreased by adjusting the dampers. Danger due to the explosive nature of the gases is thus eliminated.

Some industrial processes use powdered coal as a fuel. It is economical, because cheap grades of coal can be pulverized and inexpensively fed to the fire by being blown through pipes with blasts of air. Even and complete combustion is assured.

The Bunsen principle is applied in the gas burner and the oil burner. An examination of one of the burners of a kitchen gas stove reveals how this principle operates. In front of the burner are the gas entrance and the vents through which the air is introduced to support the combustion. The air and combustible gas pass through a mixing chamber and thence to jets where combustion takes place. The type of burner in common use was invented in 1855 by the German chemist, Robert Bunsen.

If too little air is mixed with the fuel gas, the combustion is incomplete, and glowing particles of unburned carbon are set free.



Mechanical stokers feed fuel to the fire at the rate at which it is consumed.

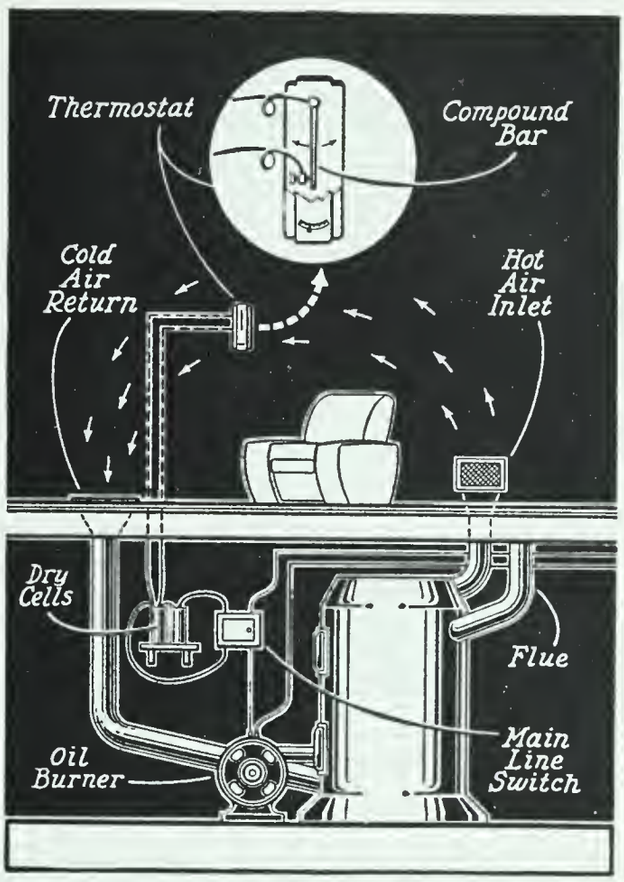
In such cases, the flame is yellow, and the particles deposit as soot on cooking utensils. Too much air makes the flame noisy and likely to "strike back." When the size of the air vents has been regulated correctly and the burner is clean, the gas burns with a quiet blue flame.

In the oil burner, the fuel is atomized (broken up into small droplets) and the spray mixed with air. It is then vaporized and burned in passing through the furnace. While the cost of equipment for burning oil is greater than that for burning gas, the fuel bill is generally less. The amount of noise developed during operation, the cost, and the availability of service when needed are items which should be checked before purchasing this or any kind of mechanical heating device.

Greater comfort and economy can be obtained from any heating system by the installation of automatic controls. The burning of solid fuels has been made more automatic and convenient by the invention of mechanical stokers. Sometimes they reduce the fuel bill by making possible the use of a cheaper grade of fuel than was used when the furnace was stoked by hand. The "underfeed" stoker, which brings the fuel to the bottom of the fire bed from the bin or hopper, is the type most commonly used. Some stokers automatically remove the ashes.

Thermostats are part of the standard equipment when gas, oil, or stokers for coal are used. A nearly constant temperature can be maintained in a dwelling by means of thermostats which indirectly regulate the rate at which the fuel burns. They do this by operating electric switches which control motors for opening and closing drafts, supplying fuel, etc. Other controls prevent over-

heating of the burner and dangerous steam pressures. These devices can be installed on systems fired by hand and are usually a profitable investment.



The compound bar of the thermostat usually consists of strips of two different metals securely fastened together. The bar bends to the right or left due to unequal expansion or contraction of the two metals with temperature changes. With the help of the text, can you complete the explanation of how the thermostat controls room temperature?

• HAZARDS IN USING FUELS

While we have stressed the importance of care in handling fuels as a matter of economy, carefulness is even more important from the viewpoint of personal well-being. Man's knowledge of the poisonous nature of the gases from combustion is practically as ancient as his acquaintance with fire itself. The writings of Plutarch record how Catalus, after being sentenced to death, committed suicide by shutting himself up in a room with the vapors from many glowing coals. The gas produced by combustion is still a common cause of death.

Carbon is the most important element to be considered in connection with the effects of the products of combustion upon health. Its complete combustion yields carbon dioxide, which is not poisonous; its incomplete combustion forms carbon monoxide, which is extremely poisonous. Breathing air containing 9 parts of carbon monoxide in 10,000 parts of air produces headache and nausea, while life, itself, is imperiled when the carbon monoxide content increases to 15 parts per 10,000 parts of air. Unfortunately, this gas has no odor to announce its presence.

The following summary, which appeared in the *Ohio Health News,* lists the cases of carbon monoxide poisoning which occurred in Ohio during a typical six months' period from October to March and indicates the common sources of this hazard to human health.

INCIDENTS OF CARBON MONOXIDE POISONING

Domestic Appliances

	Males	Females	Fatal	Nonfatal	Total
Gas heaters					
Bathroom heater	9	14	4	19	23
Other room heaters	30	8	20	18	38
Cooking stove	12	15	2	25	27
Furnace	....	2	....	2	2
Water heater	11	15	6	20	26
Others	3	10	1	12	13
Not specified	25	17	14	28	42
Escaping gas	23	11	4	30	34
Oil heater	2	....	2	....	2
Coal or cook stove, furnace	27	28	5	50	55
Charcoal (in buckets, etc.)	4	....	....	4	4
Washing-machine gasoline motor	2	3	....	5	5
Cinder pump	3	2	1	4	5
Smoldering carpet, mattress	2	1	3	....	3
Electric motor (burned out)	3	6	....	9	9
TOTAL	156	132	62	226	288

Motor Vehicles

	Males	Females	Fatal	Nonfatal	Total
Residence garages	56	7	28	35	63
Public garages	17	....	1	16	17
En route, or "outside"	37	6	11	32	43
Others	5	....	1	4	5
TOTAL	115	13	41	87	128

Carbon monoxide has a very much greater tendency than oxygen to unite with hemoglobin—the red, oxygen-carrying constituent of the blood. Therefore the oxygen gets little chance to combine with hemoglobin when both gases are present in the air. Thus a person who breathes both suffers a form of suffocation even though he continues to breathe. Experiments have shown that it is even more harmful to breathe a small concentration of this poisonous gas over a long period of time than to breathe a relatively high concentration of it for a short time. An investigation in which two hundred automobiles were stopped at random revealed that 5 per cent of these cars contained a dangerous concentration of this gas and that half of them contained traces of it. This need not be the case. It is the owner's responsibility to keep his automobile in good repair. The exhaust system requires frequent checking to make sure that its parts are tight-fitting. Repair or replace leaky gaskets and connections immediately. Carburetors should be properly adjusted and the ignition

system must function efficiently to prevent faulty combustion of the fuel with its resultant increase in carbon monoxide production. Permit no openings between the engine and the driver's seat through which gas can enter the interior of the car. Likewise, make sure that the floor boards are gas-tight and properly covered. The National Safety Council advises that an occasional stop be made for a "breathing spell" when one is making a long motor trip.

In cases where carbon monoxide poisoning has occurred, apply artificial respiration at once. Give hot coffee to the victim after he has regained consciousness; summon a physician at once.

There are many hazards in the use of household appliances involving gas, gasoline, and kerosene. Gasoline is too hazardous to be used indoors for any purpose whatsoever except by an expert. Its vapor will ignite not only from flame but also from such unpredictable occurrences as an accidental electric spark, a spark of static electricity, or the breaking of an electric lamp. Gasoline stoves are extremely hazardous for ordinary home use, even when equipped with so-called modern safety devices—regardless of what the manufacturer, merchant, or mail-order catalogue may say to the contrary. Avoid using gasoline stoves, indoors or out, near easily combustible materials. In spite of all precautions, the consumer is very likely to get leaded gasoline at least part of the time when purchasing this fuel for use in lamps, stoves, or other appliances. Remember that there is danger of lead poisoning in repeated exposure to the vapors of such gasoline and to the gases produced when it burns.

In selecting a gas appliance, only those bearing the Laboratories Approval Seal of the American Gas Association should be considered. This seal indicates that certain features assuring safety, efficient operation, and durable construction have been built into the appliance. All models displaying this seal are required to comply with standards adopted by the American Standards Association, the leading agency for the development of all types of industrial, commercial, and consumer standards. Today there are such standards for practically every domestic gas appliance. It is estimated that 95 per cent of all such equipment sold in the United States and Canada displays the Laboratories Approval Seal.

The "CP" (certified performance) marking on some domestic gas ranges indicates that they possess some twenty-odd quality features over and above those required by national standards. The first specification is that they be tested and approved by the Amer-

ican Gas Association Testing Laboratories. Others are essentially those covering convenience and speed.

Housewives should be familiar with the general characteristics of a properly adjusted gas flame. To obtain best results all burners should be properly adjusted. They should not be overrated; for example, the flames of a top burner should not lick up around a utensil placed over it. The local gas company is usually willing to make without charge any necessary adjustments on domestic gas equipment. It can also advise its consumers in the proper operation and care of gas equipment.

After boiling starts it is an economical practice to lower the flame so as just to keep boiling active. Vigorous boiling yields no higher temperature than boiling at the minimum noticeable rate. There is no advantage in the former except for certain uses, as in boiling down jellies. Some top-burner valves are equipped with stops to indicate when enough gas is being supplied for simmering purposes. Other top burners are equipped with separate simmer sections. For rapid heating, some ranges are provided with giant burners.

Among many other features available on modern domestic gas ranges are thermostats for accurately controlling any desired baking temperature in the oven. Some are capable of maintaining temperatures as low as 250° F., recommended when preparing certain foods.

There are no verified claims for "gas savers." There are two common types of these devices. The first is intended for placing over top burners of a range; the second is attached at its outlet. Investigations made by the American Gas Association Testing Laboratories and by the National Bureau of Standards reveal that none of these devices accomplish what is claimed for them and that many constitute a definite hazard.

Kerosene stoves, water heaters, and similar appliances also always present the danger of fire. A large percentage of accidental fires in rural districts come from kerosene stoves. Exercise extreme caution in operating them, and see that all unnecessary fire hazards are removed from their vicinity.

In America, fire destroys someone's dwelling every two minutes and causes a horrible death at an average of once every hour. Some idea of the magnitude of the destruction caused by fire can be obtained from the following quotation from a circular issued by the National Bureau of Standards: "It is difficult to visualize the extent of the life and property losses from fire. The $500,000,000

COMMON PRECAUTIONS AGAINST FIRE



Courtesy The Quarrie Corporation



Courtesy New York Sun

A terrific blast caused by the ignition of vapors from dry-cleaning fluid resulted in this wreckage. Three persons were killed and twenty-two injured. The force of the blast was felt twelve stories above and a block away.

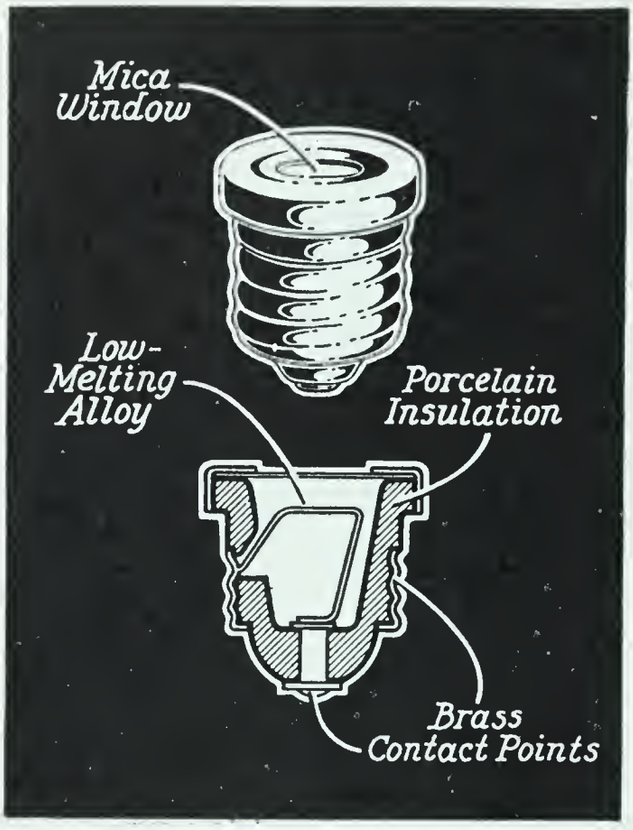
annual property loss can be represented by the fire ruins of dwellings placed in a solid row on one side of a highway extending from New York to Chicago, a distance of about 900 miles. An observer in an automobile would require, perhaps, three days to travel the length of this avenue of desolation. At intervals of 600 feet, or at the rate of three or four a minute, there would be seen the graves of fire victims, mostly women and children, who died from burns, suffocation, panic, or other cause directly attributable to fire." While this is a true picture for the 1920-1930 period, there was fortunately almost a 50 per cent drop in fire losses during the next ten years. No doubt more adequate knowledge and enforcement of preventive measures have been partly responsible for this reduction.

Most fire losses can be traced to carelessness and ignorance. The greatest threat of fire is directed against the home, but industries likewise are hard hit. The leading causes of fires are listed by The National Board of Fire Underwriters as follows:

Exposure from other buildings, including conflagration
Matches, smoking
Chimneys, flues, and stacks—overheated or defective
Misuse of electricity and electrical devices
Incendiarism (setting fires)
Petroleum and its products
Sparks on roofs
Stoves, furnaces, boilers, and their pipes
Spontaneous combustion

Fires resulting from spontaneous combustion appear to have no cause at all, but there is really nothing mysterious about them. Although haystacks, soft coal stored in bunkers, and rags greasy with animal or vegetable oils sometimes begin to burn automatically, the reason for their doing so is well-known. Even when oxidation takes place slowly, heat may be liberated faster than it is carried away if there is little air circulation through and about the oxidizing material. The temperature thus increases, and oxidation becomes more rapid. Consequently the rate of heat liberation becomes more and more rapid until finally the kindling temperature is reached, and the material bursts into flames. As soon as one understands that these conditions lead to spontaneous combustion, it becomes easy to make rules for its prevention. For example, greasy rags either should be kept in fireproof metal containers or should be disposed of by burning.

Dust explosions constitute another common type of disaster easily explained in terms of oxidation. Since union with oxygen takes place at the surface of any burning solid, to subdivide the material means to increase the amount of surface exposed and thereby allow oxidation to take place more quickly. Common experience with kindling wood verifies this statement. Powdered materials or dusts may present enough surface to allow such rapid oxidation that an explosion results. By the process of combustion these small particles are almost instantly changed into gases having a volume many times greater than that of the original materials. It is the sudden great increase in volume that causes the explosive effect. Loss of life and property has often occurred because of dust explosions in coal mines, in grain elevators, in



How does the fuse prevent overloading electrical circuits?

cork and sugar factories, in flour mills, and around threshing machines. Inflammable liquids and combustible gases likewise present the hazard of fire and explosion.

The use of electricity for any purpose at all involves fire hazards. When electricity flows along a conductor, some of it is changed into heat. This transformation is just what is wanted and arranged for in the electric stove; it spells disaster when it takes place to any considerable extent in the wiring of a building. Even though copper is the second best conductor of electricity among the common metals, there is a definite restriction to the amount of current that a wire of given size can safely carry. If excessively overloaded, the wire will heat and melt, but the likelihood is that some combustible material in its vicinity will have been set on fire long before this happens. Homes are protected from this hazard by means of fuses. A fuse is a piece of easily melted metal placed in the circuit so that all the current used must pass through it. When the amount of current exceeds a certain maximum, usually 10 to 15 amperes, the heat developed melts the fuse link and the circuit is broken. Since the "blowing" of the fuse produces a small electric arc which might set fire to any combustible material near-by, the strip of fuse metal is encased in a fireproof container called a fuse plug.

There is also the danger that the amount of current in the line will suddenly become dangerously large, because somewhere there is a path of little resistance called a "short circuit." This is often caused by two parts of the circuit touching one another or being joined by some conductor, usually metal. To prevent short circuits, wire wrapped with nonconductors like cotton, wool, silk, and rubber is used; usually, the insulated wire is also placed in metal pipes or conduits or is covered with a flexible metal sheath. Mice and rats have frequently caused short circuits and fire losses by gnawing away the insulation when the precaution of encasing

wires in metal was not taken. Such an omission is false economy.

When a fuse "burns out," it should be replaced by one of the same current capacity. The repeated melting of replacement fuses indicates that there is a short circuit in the line, provided that too many appliances are not being used at the same time, and an investigation should be made by a qualified person. Do not replace a fuse by a piece of ordinary metal. Do not replace burned-out fuses by others of greater current-carrying capacity. Even though the law may require that the wire used in a building be of a certain size, that it be in conduits, and that there be periodic inspection, these precautionary measures will not help much if substitutes for specified fuses are used by uninformed persons or by others who wilfully use them even though they know better.

• CONTROL AND PREVENTION OF DESTRUCTIVE FIRE

The knowledge which has enabled man to produce more efficient combustion has also suggested three ways in which fires can be extinguished. These are (1) by preventing oxygen from reaching the fuel; (2) by cooling the burning fuel to below its kindling temperature; (3) by removing the fuel, as when fighting forest fires.

In comparison with other substances, water has the highest heat capacity—that is, it absorbs a large quantity of heat when its temperature is raised and when it is subsequently changed into vapor. It therefore has a great cooling effect on burning materials upon which it is thrown. In addition, either as liquid or steam, it tends to blanket a fire and in this way to smother it. These properties, together with its availability in large amounts, explain why water is the most important fire-extinguishing agent. Commercial fire extinguishers are adapted to special types of large fires or are used on small fires because of their convenience.

The soda-acid extinguisher is a very common type of fire extinguisher. It contains a large volume of sodium bicarbonate solution and a small bottle of sulfuric acid. The latter has a loose-fitting stopper which drops out when the extinguisher is inverted when used, thereby permitting the two chemicals to react. Carbon dioxide is formed very rapidly by the reaction and its pressure forces a stream of liquid from the nozzle of the fire extinguisher. This stream of solution consists principally of water and has a cooling effect on the burning material. On fine fabrics, silks, upholstery materials, and similar fabrics, the stream from the soda-



Courtesy American-LaFrance and Foamite Industries, Inc.

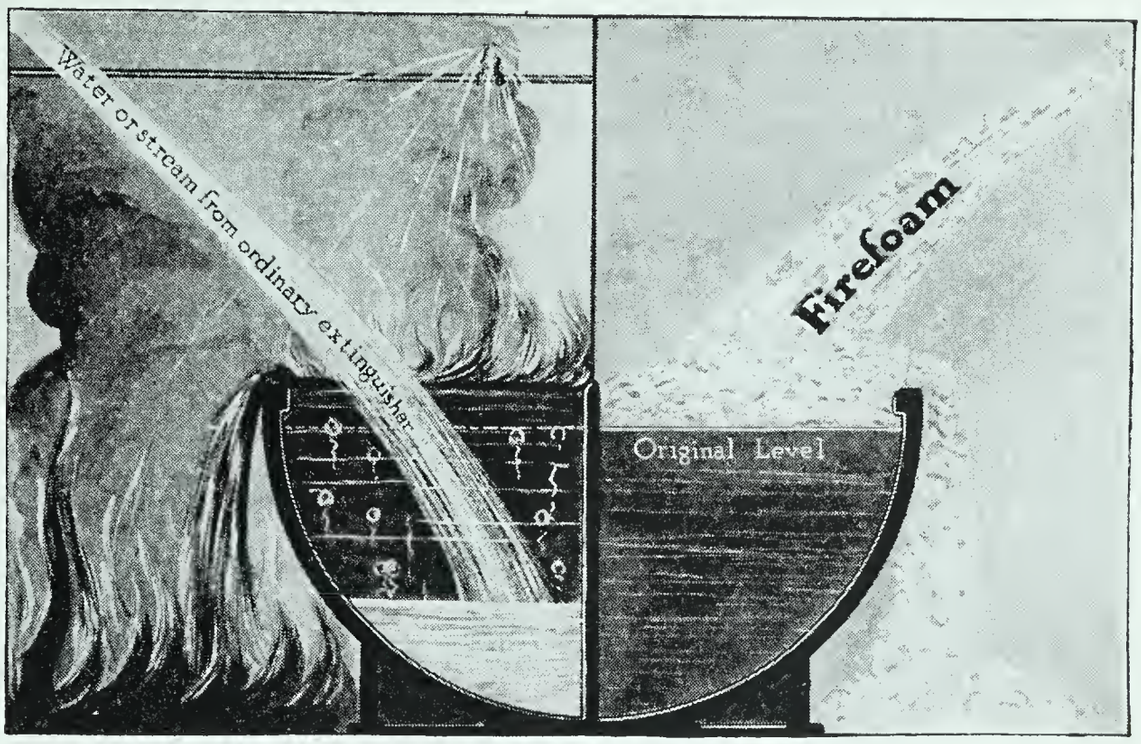
Sectional view of a soda-acid fire extinguisher is shown above.

acid extinguisher frequently has a staining and sometimes a destructive effect. The stain is caused by the presence of sodium bicarbonate and sodium bisulfate in the solution. The destructive effect is caused by free sulfuric acid which has not completely entered into the reaction with the sodium bicarbonate. This extinguisher is ineffective against oil fires because, like a stream of water alone, it serves only to scatter the burning oil, since oil is less dense than water and floats upon it. It is also dangerous to use the soda-acid extinguisher on fires caused by short circuits or where the stream might fall on live wires or conductors, because the solution forced out of the extinguisher is a good conductor of the electric current.

There are types of fire extinguishers on the market, similar in appearance, action, and effectiveness, employing a small cartridge of compressed carbon dioxide gas to expel the water. The seal in the top of this cartridge is pierced when the extinguisher is inverted, thus releasing the gas at full pressure to drive out clear water. The absence of reacting chemicals eliminates the possibility of chemical damage which is ever-present in the older type of soda-acid unit.

The foam-type fire extinguisher is very effective in combating oil and gasoline fires. Its action is very similar to that of the soda-acid extinguisher. Here the carbon dioxide is produced by a reaction between solutions of sodium bicarbonate and aluminum sulfate. The sodium bicarbonate solution also contains a small amount of foam-making material, which is sometimes extracted from licorice root. When mixed, the solutions react to form a thick, tough foam which is capable of floating upon oil and many other inflammable liquids. The countless bubbles of foam, which are filled with carbon dioxide, blanket the burning surface, excluding the oxygen of the air which is essential to the combustion. It is inadvisable to use foam on fires involving energized electrical equipment; the presence of water in the foam makes it a conductor.

In oil fields and at refineries, large quantities of the prepared solutions are stored separately. When a fire is discovered, they are pumped to a mixing chamber, from which the freshly made foam



Courtesy American-LaFrance and Foamite Industries, Inc.

Comparative effects of water and of foam on a tank of burning liquid.

passes through a system of pipes to the place where it is needed.

A type of fire extinguisher commonly carried by trucks and automobiles is really a force pump filled with carbon tetrachloride. This type is also satisfactory for home use. The carbon tetrachloride evaporates quickly when sprayed on a fire and forms a blanket of vapor which is more than five times as heavy as air. It will neither burn nor support combustion. This is the same liquid which in large measure constitutes many noninflammable spot-and-stain removers sold under various trade names. Since carbon tetrachloride is a nonconductor of electricity, this type of extinguisher may be safely used on electrical fires. It need not be large to be effective in extinguishing small fires and is therefore convenient as well as serviceable. When carbon tetrachloride is heated in the presence of air, phosgene, a poisonous gas, may form. Therefore, a room in which a carbon tetrachloride extinguisher has been used should be ventilated as soon as possible. If any part of the contents of a carbon tetrachloride extinguisher is discharged, refill it immediately to prevent any possibility of corrosion by the presence of moisture in the air-filled space previously occupied by the carbon tetrachloride. Such moisture may combine with the carbon tetrachloride to form a dilute acid of highly corrosive character. Why is this undesirable?

The use of carbon dioxide itself has been a more recent development in fire fighting. The gas is kept in the liquid state under



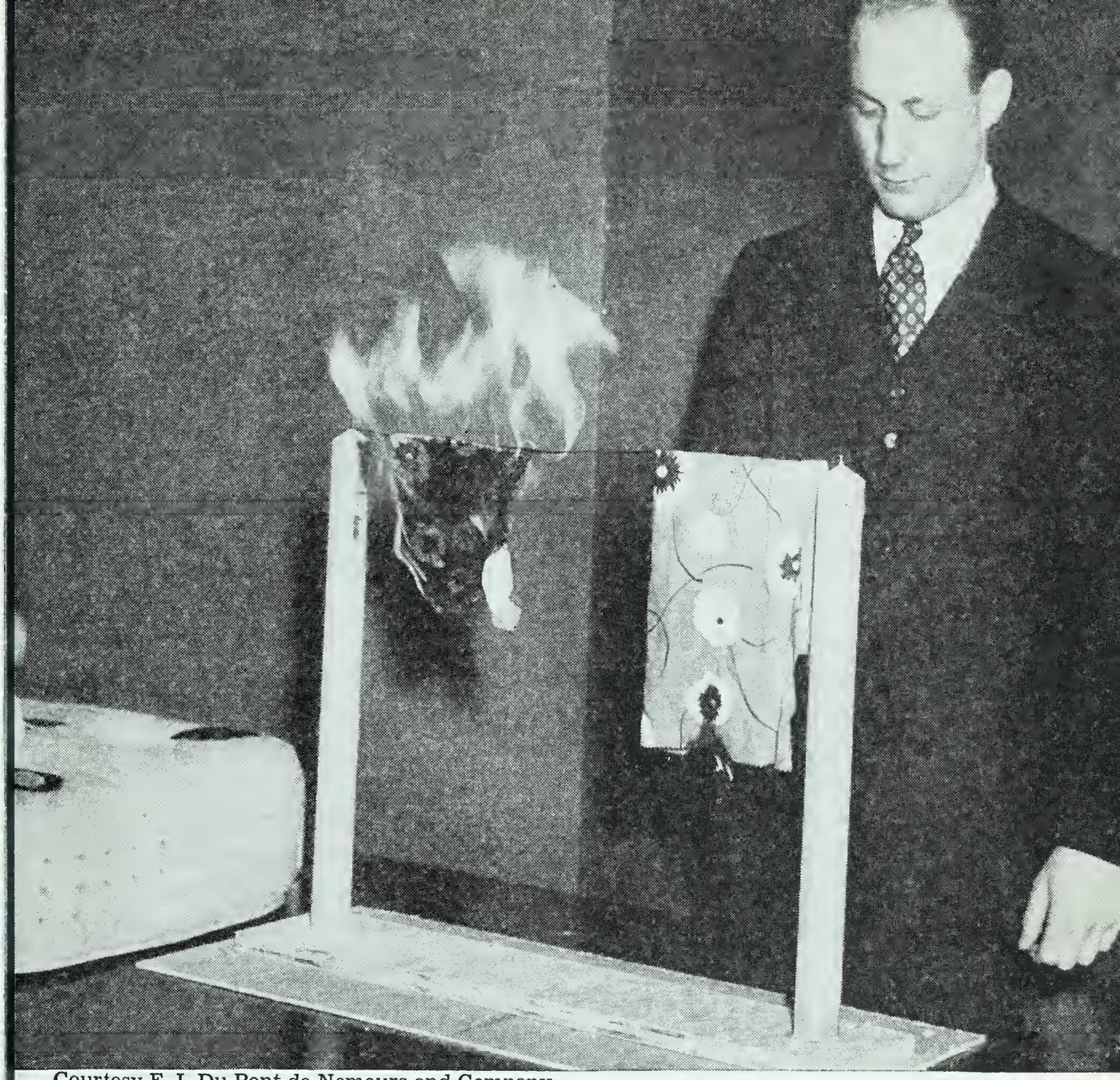
Courtesy Walter Kidde and Company, Inc.

An automobile fire can be put out with a carbon dioxide extinguisher. When released, the liquid furnishes 450 times its stored volume of gas, which will not support combustion.

pressure in steel containers. When permitted to escape into the atmosphere, it begins to vaporize quickly, enveloping the burning material in a smothering blanket of air which has been diluted with carbon dioxide so that its oxygen content is below the point which supports combustion (ordinarily about 15 per cent). Like the carbon tetrachloride extinguisher, the carbon dioxide extinguisher can be safely used on electrical fires. It has the added advantage of leaving no damaging residue after the fire has been put out. The principal use of carbon dioxide fire-fighting equipment throughout the world is on inflammable liquid fires of all kinds.

A grease fire, like burning oil, is scattered—and not extinguished—by a stream of water. Sprinkling with baking soda, or even table salt, is a simple but effective way of extinguishing the flames of burning grease, as in deep-fat frying or in broiling. Authorities recommend that for a home to be completely equipped against fire, there should be a carbon dioxide extinguisher available for use on fires in the kitchen involving grease; in the basement for fires about the oil burner; and in the garage for fires that concern the family automobile. It should also have available a water extinguisher employing the carbon dioxide cartridge method of expulsion to combat fires in materials such as clothing hanging in a closet, a mattress, heavy upholstery, and the like.

Automatic sprinkler systems have been designed to stop fires before they gain dangerous headway. Sprinklers are spaced more or less regularly in piping extending along ceilings. A low-melting alloy, or other device, prevents the flow of water from the system under ordinary conditions. If the temperature rises to a predetermined degree above normal, such as would be caused by a fire, water is released into the affected area by the melting of the alloy or the operation of some other similar device.



Courtesy E. I. Du Pont de Nemours and Company

A flameproofing agent does not alter the "feel" or texture of the fabric to which it is applied. At the far left is a treated mattress on which some gasoline was poured and ignited. The mattress scorched but did not catch fire. An untreated fabric is shown in flames, while at the right a treated fabric to which a match was held scorched but did not flame.

There are, of course, other simple ways of putting out fires. The essential air may be excluded from a fire by covering the burning material with earth or sand. When a person's clothing catches on fire, some quickly available object, such as a coat or a rug, can be used for wrapping about the body to smother the flames. Can you think of any way of extinguishing a fire which does not exclude oxygen, cool the burning material below its kindling temperature, or remove fuel from the path of the fire?

It is more important to prevent fires than it is to be able to extinguish them after they are once started. A building cannot

be made absolutely fireproof, because there are no available building materials which will withstand fire beyond all limits. There are, however, fire-resisting materials which greatly lessen the fire hazard. The occasional destruction by fire of buildings made even of these materials, although infrequent, indicates that there is no good substitute for carefulness.

Wherever practicable, it is advisable to construct with noncombustible materials, such as brick, stone, tile, slate, concrete, and steel. Metal laths and slate shingles, for example, are preferable to wooden ones. When cost or other factors make the use of wood or other combustible materials advisable, hollow air spaces and cracks should be avoided, as they speed up the burning process once a fire is under way.

Extra protection can be gained by fire-retardant treatment of the woodwork, by covering it with plaster boards, and by the use of fire-retardant paints. Partitions and doors of noncombustible materials may be used to prevent the spread of fire from one section of a building to another.

Curtains, draperies, and other fabrics are often of such a nature that they can be flameproofed without destroying their beauty or usefulness. Borax, ammonium phosphate, and alum are representative of the materials used to prepare the solutions into which the fabrics are dipped. Although materials treated in this way may be scorched after continued contact with a flame, the time required for their burning is much greater than in the case of untreated fabrics. Flameproofed fabrics were used in the 1939-1940 fairs in New York and San Francisco. Some communities have ordinances requiring that fabrics used in public buildings, such as schools, churches, and theaters, be flameproofed.

Another effective precautionary procedure is periodic inspection. Unfortunately, we may think it is too simple to be worth while. In cities, laws usually require such inspection of public buildings. One may find previously unnoticed hazards when he inspects the chimney for open masonry joints, particularly if there is no flue liner. Remove deposits of soot regularly since they cause deterioration of the chimney as they burn and produce sparks which escape to the exterior. Accumulations of combustible waste materials found in the attic, cellar, or other parts of the home, provide fuel which may be ignited by spontaneous combustion or by carelessly discarded smoking materials. Store greasy and oily rags in tightly closed metal cans provided for the purpose. Keep rubbish and ashes from the furnace in separate metal con-

tainers until they are discarded. A complete check list of the things to be looked for in a systematic inspection may be obtained from the local fire department, from fire-insurance companies, or from The National Board of Fire Underwriters, New York City.

• IN CASE OF FIRE

The fire department does not want you to wait until your own efforts and the efforts of other volunteers have failed to extinguish a fire before calling upon it for help. Unless it is obvious that a blaze is so small that it can be put out quickly with the fire extinguisher, sand, earth, or other materials at hand, summon the fire department at once. Too often have people been certain that "we can handle the situation ourselves," only to realize later that delay in summoning aid had given time for the flames to make disastrous headway.

Familiarize yourself with the method of sending in a fire alarm by telephone, at the street box, or by local arrangements. Remember when calling by phone that enough time must be taken to give the exact location of the fire. When the box system is used, tell someone to remain near-by to direct the firemen to the scene of the fire.

To keep cool mentally amid the excitement of a fire is not only possible but essential. When panicky, hundreds of people have sometimes perished in auditoriums, because they blocked the very exits whose opening would have meant safety to all. Likewise, excited persons often telephone inadequate or misleading information when asking for assistance from the fire department or hang up before they can be questioned about the location of the fire.

When actually combating the flames, take a position from which there is a sure way of escape and where there is no danger of suffocation. More deaths result from suffocation and from inhalation of the fumes than from burning. It is a good procedure to tie a wet cloth over the mouth and nose when exposed to the flames and smoke. The purest air in a smoke-filled room is found near the floor, because of the circulation caused by the rise in temperature. In passing through such a room, keep close to the floor and breathe as little as possible. Close doors and windows wherever possible to confine the blaze and restrict the air supply; this helps smother the fire.

If your clothing becomes ignited in spite of all precautions, remember that the first danger is that you will inhale the flame or

hot gases. Many have lost their lives because they became excited and fanned the fire by aimless running. Remove the burning article of clothing if it can be done quickly. Otherwise, smother the flames by rolling in a blanket, rug, coat, or other suitable article which may be available. Water should be applied if it is handy. When the flames have been extinguished, drench the clothes with water, but do not remove the garments until an ointment has been obtained for application to the burned areas of the body. Be careful not to tear the burned skin and thus allow entrance to bacteria, which may cause infection.

Scalding by hot water or steam is so frequent an occurrence that everyone should be careful in handling these useful materials. Do not leave containers of hot or boiling water within the reach of children. It is hazardous, even for an adult, to carry a child in one arm and a vessel of boiling water in the other. Children withstand severe burning poorly. This fact and the frequency of such accidents in which children are victims explain why about 45 per cent of the deaths from burns are those of persons less than six years of age. About three out of five deaths from burns are of women and children.

A number of different applications have proved helpful in the treatment of minor burns. Among the best are a dusting powder made by mixing boric acid and starch; a wet dressing of a thick paste of bicarbonate of soda, strong tea applied as a wet pack, or a warm poultice of tea leaves. Special preparations are available at drugstores. Ask your doctor which one you should keep on hand.

Very severe burns should be treated by a physician at once if possible. When the suffering makes it impossible to await the arrival of the physician before treatment is begun, a very satisfactory first aid is the wet dressing made from tea. Greases and powders should not be used on serious burns.

Exercises for Problem Study and Review

1. In what ways may faulty combustion of the fuel add unnecessarily to the cost of heat production in your home?
2. What are the advantages and disadvantages of using the smaller sizes of solid fuels? Why should an area of uncovered, glowing fuel be left after each firing of solid fuel?
3. Compare the methods used in firing a furnace with (1) anthracite coal, (2) coke, and (3) bituminous coal.
4. If cost were not a factor, which fuel would you choose for heating a dwelling, (1) anthracite coal, (2) coke, (3) gas, (4) or oil? Give

reasons for your answer. What disadvantage is the mechanical stoker meant to overcome?

5. What are the parts of a Bunsen burner? How does it function? What does a yellow flame indicate? A noisy flame? A quiet blue flame? What is meant by "striking back" of the burner?

6. How does the oil burner resemble the gas burner? What disadvantages does it have which are not found in the gas burner? What advantage does the use of oil frequently have over the use of gas?

7. Criticize this statement: "Thermostats and other automatic controls are profitable investments only when automatically fired furnaces are used." Include reasons for statements which you make.

8. Compare carbon dioxide and carbon monoxide as to (1) production during combustion of fuels; (2) effect upon human beings.

9. About what percentage of cases of carbon monoxide poisoning is fatal? Why is the presence of carbon monoxide difficult to detect without special equipment? In the table on page 58, what percentage of all deaths from carbon monoxide poisoning was traceable to the automobile?

10. To what can the causes of most fire losses be traced? List five very common causes of destructive fires. Make a list of rules which would help prevent such fires if they were carefully followed.

11. What conditions favor spontaneous combustion? What are the possibilities of spontaneous combustion often found around the home?

12. Dust explosions are ever-present hazards in coal mines, flour mills, and sugar factories but not in limestone quarries or cement mills. Why? What dusts might present such hazards around the home?

13. Explain the action of fuses. Why is it dangerous to overload a conductor with electric current? Why is a short circuit hazardous? In what additional ways may the house wiring be protected in order to prevent fires?

14. What should be done when fuse replacements continue to "burn out"? Why should they not be replaced by a coin or other metal or by a fuse of greater capacity for carrying current?

15. What are the three general ways of extinguishing fires?

16. Explain the action of the soda-acid fire extinguisher. Should it be used on fires in the vicinity of "live" wires? Explain.

17. Why is the foam-type fire extinguisher really a modification of the soda-acid type?

18. Why is carbon tetrachloride so useful in putting out small fires? Is it safe to use a carbon tetrachloride extinguisher on electrical fires? Explain.

19. Where are the fire extinguishers located in your school? What kind are they? How should they be operated when used? How often are they inspected?

20. What is the most important fire-extinguishing substance? Why?

21. Name two other ways of extinguishing fires and show how they make use of one or more of the principles listed in question 15.

22. How do automatic-sprinkler systems work? Should they affect the cost of fire insurance? Explain.

23. Why is no building absolutely fireproof?

24. What are two ways of obtaining extra protection in places where combustible materials are used?

25. Make a list of eight rules that would decrease the number of destructive fires each year if they were followed by everyone.

26. Should the fire department be summoned when a small fire has been discovered? Give reasons for your answer.

27. How would you get help if you discovered that your home or school was on fire? What would be your exact message if you had to call the fire department by telephone?

28. What would you do if you discovered a fire in a crowded theater or auditorium?

29. Make a list of rules that should be followed while one is helping to extinguish a fire in a burning building.

30. What would you do if your clothing became ignited while you were helping to extinguish a fire?

31. If a person's clothing were ignited, what should you do after you had succeeded in extinguishing the flame?

32. Make a list of unnecessary practices commonly seen in homes which you would list as dangerous because they sometimes lead to injury, death, or property loss by burning.

Problem 4: How does man control the transfer of heat?

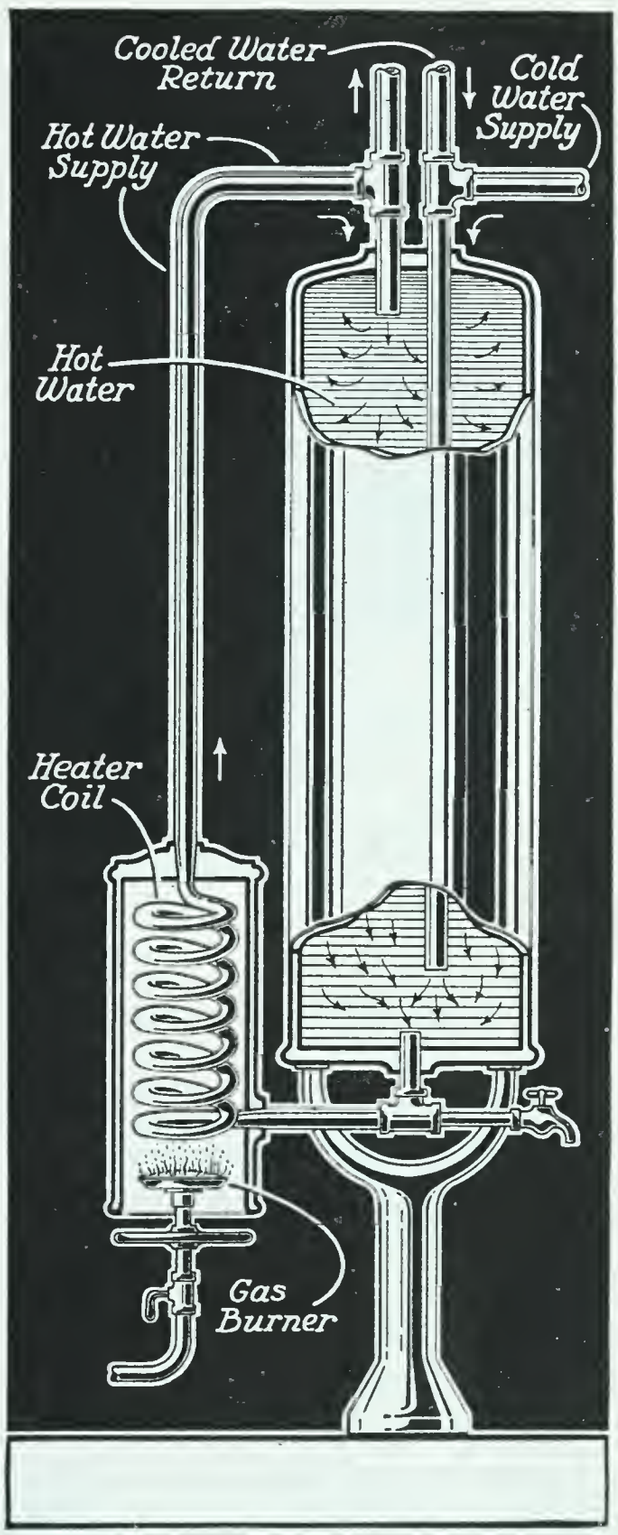
• MODES OF HEAT TRANSFER

An understanding of the methods of heat transfer is necessary to a study of man's adjustment to the problem of maintaining a healthful and comfortable atmosphere indoors. There are three methods of heat transfer—conduction, convection, and radiation.

If one end of a metal bar is heated in a fire, the bar soon becomes hot throughout its entire length. The molecules—small particles of which matter is composed—at the one end of the bar have their activity speeded up by the absorption of the heat energy. Since heat flows from regions of higher to those of lower temperature, some of the applied energy passes progressively from molecule to molecule in the direction of the cooler end. The tendency

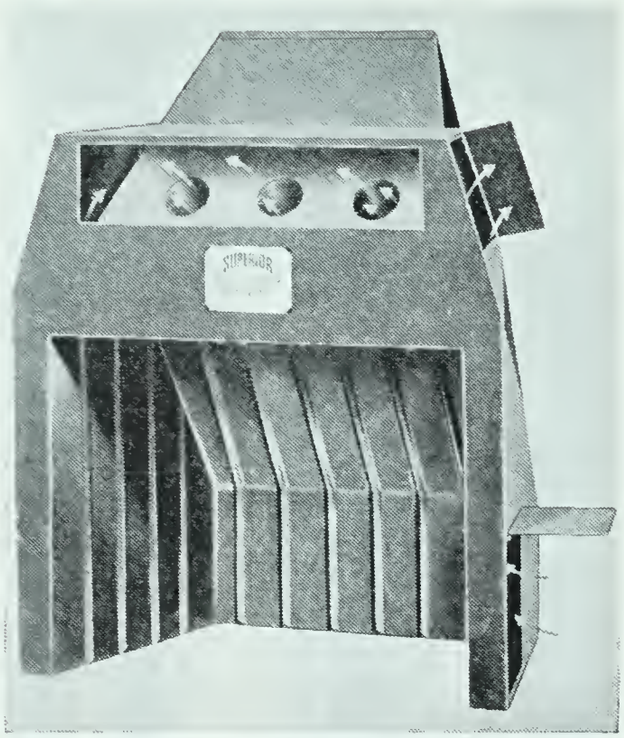
is to bring all portions of the bar to the same average molecular activity, or temperature. This method of heat transference is called *conduction*. Some materials, like the metals, are good conductors of heat; others, such as wood and asbestos, conduct heat poorly—so poorly in fact that they are called *insulators*.

When gas or liquid receives heat from a hot surface, it expands, becomes lighter per cubic foot, and rises. Cooler, and therefore heavier, portions adjacent to the heated fluid settle and push the less dense, warmer portions upward. In this way, circulation is brought about and heat energy is carried upwards by currents, called *convection* currents, within the gas or liquid. This explains why the warmest air in a room is ordinarily found near the ceiling, and the coolest air near the floor. The efficiency of fireplaces has been greatly increased in recent years by means of vertical metal channels embedded in the outer structure of the fireplace. When the linings of these channels become hot by means of conduction, they in turn heat the air within, the convection currents result. In this way, much heat is captured which otherwise would have gone up the chimney. Stoves make more effective use of fuels than fireplaces because of the greater opportunity they provide for convection heating.



What is the role of convection currents in the hot-water heater?

When you stand before an open fire, you are warmed on the side nearest the flames. Likewise, if you hold your hand about a



Courtesy Superior Fireplace Company

What science principles have been applied here to increase the efficiency of fireplaces?

foot below a hot flat iron, your hand becomes warmer. Since air is a poor conductor of heat and since convection currents tend to transport heat upward, it follows that there must be a third way in which heat is transferred. It is evident that intervening molecules of matter play no role in this third method of heat transfer when we realize that the sun sends us heat and light through ninety-three million miles of practically empty space. This method of transferring heat without the necessity of any intervening matter is called *radiation,* and this form of energy is known as radiant heat. Other things being equal, dull, black objects have the greatest capacity to absorb or give off radiant-heat energy. This is one reason for the common practice of wearing dark-colored clothing in winter and light-colored clothing in summer.

• PROMOTING HEAT TRANSFER

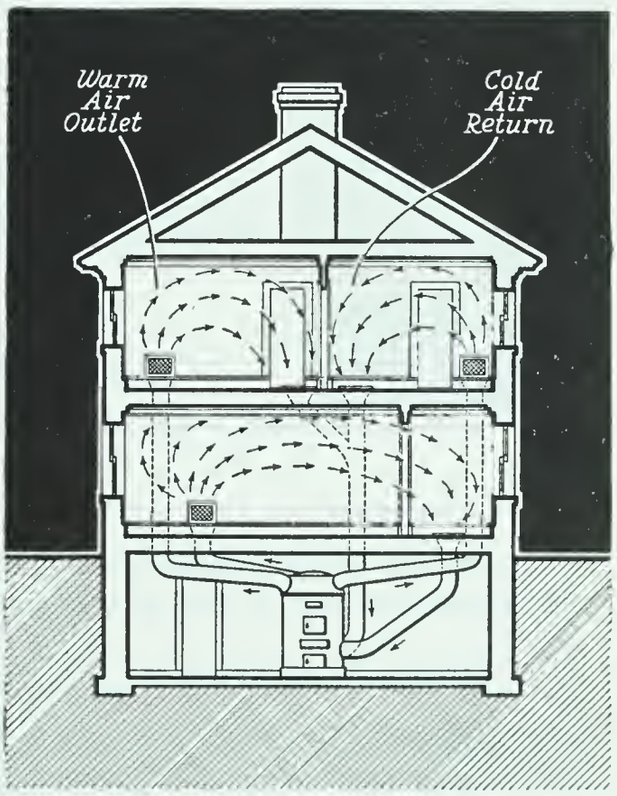
Central-heating plants are either warm-air systems or radiator systems. They are more complex than the stove or fireplace, but the methods of heat transfer are the same.

A warm-air furnace is essentially a large stove to which has been added a jacket in which air is heated by conduction, and then passed by convection to various parts of the building. In the pipeless furnace, the heated air rises to the living quarters through a register in the floor directly over the warm-air chamber of the furnace. Cold air returns by gravity and is guided to the bottom of the jacket for reheating. This type of furnace is suited to small homes where the free circulation of air from room to room is possible. Unevenness of heating is the chief disadvantage, while the low cost of installation and operation favor its adoption in homes structurally adapted to its use.



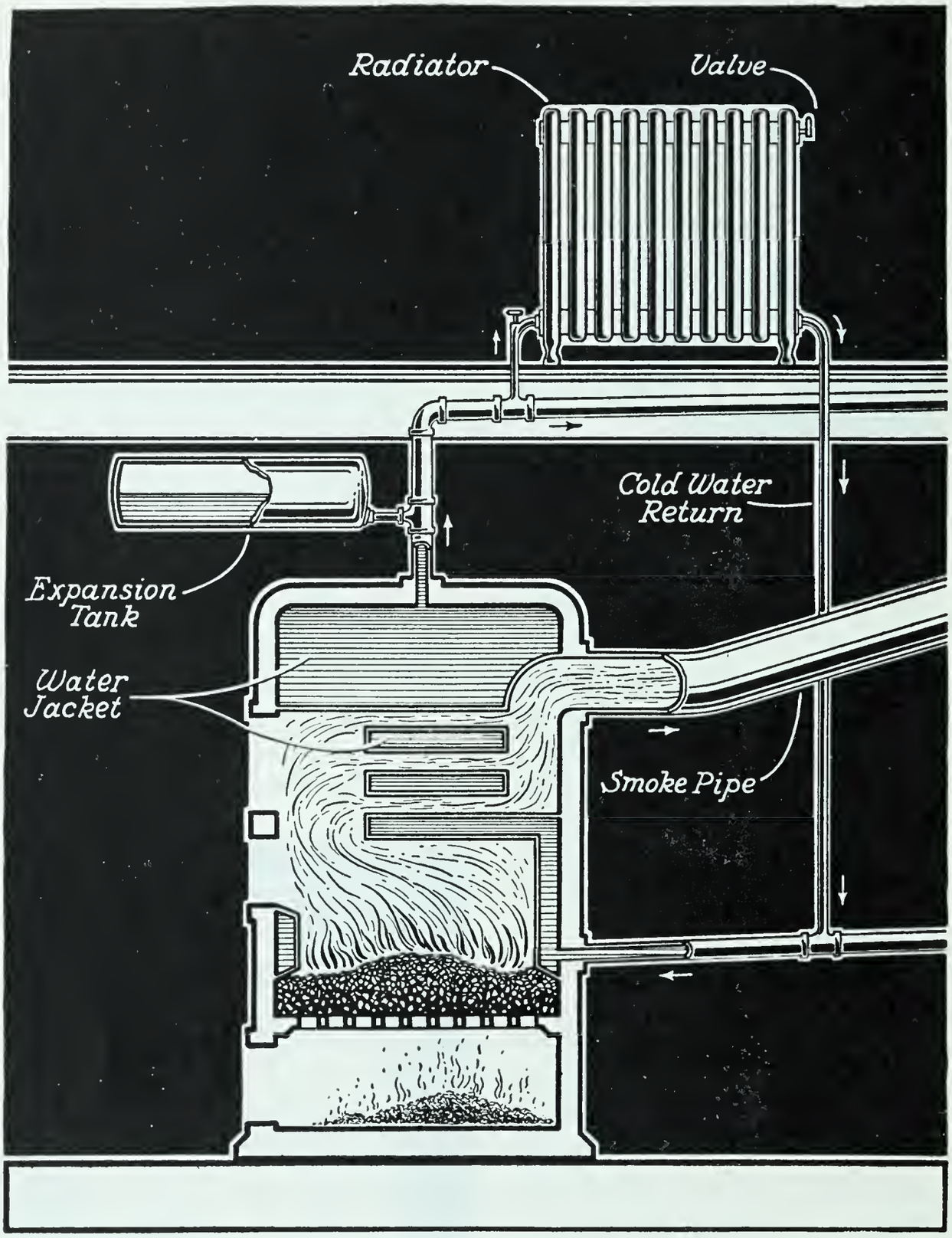
The piped warm-air furnace differs from the pipeless chiefly in that it has a separate pipe supplying heated air to each room. The warm air enters the rooms through registers at or near the floor level. As in the case of the pipeless furnace, cold air returns to the bottom of the air jacket around the furnace for reheating and recirculating. Enough fresh air normally leaks into the house or enters as doors are opened to take care of ventilation requirements. Hence, in the interest of economy, modern furnaces of this type usually make no provision for bringing in cold outdoor air.

Difficulties met in maintaining an adequate rate of heat transfer limit the use of the piped warm-air system to buildings of few stories and of rather simple floor plan. The amount of space taken up by the large distributing pipes, particularly in the basement, is sometimes a definite disadvantage. The same is true of the necessity of centrally locating the furnace and recirculating ducts. These disadvantages have been partially overcome, and the range of house designs to which warm-air systems are suited has been increased by the development of the forced-flow system; the cost of operation is greater, however. In this system, a fan eliminates the dependence upon gravity for air flow and makes possible better control of the rate of circulation. As in the case of the pipeless furnace, the piped warm-air systems have in their favor quick response, simple regulation, and low first cost.



Convection currents distribute heat in the piped warm-air system.

In radiator systems, hot water or steam is piped to radiators, which distribute the heat to the room by convection and, to a less extent, by radiation.



Compare the science principles applied in the hot-water heating system with those applied in the piped warm-air system and the steam system.

The radiators should be placed beneath the windows and in the more exposed parts of the room. Long, low, thin radiators provide more uniform heating than short, high, thick ones. While the practice of painting radiators adds to their beauty, it usually detracts from their effectiveness. Oil paints reduce the efficiency

less than metallic ones. In modern homes, the radiators are hidden in enclosures built into the walls. Ample openings must then be provided for the free passage of convection currents.

If hot water is supplied to the radiators, the furnace used differs from the hot-air furnace essentially in that the chamber above the firebox is filled with water instead of air. Obviously, the medium of heat transfer in this arrangement must be kept in a closed system and not allowed to escape into the rooms. This means that pipes are necessary to return the cooled water from the radiators to the boiler, as well as to carry hot water in the opposite direction.

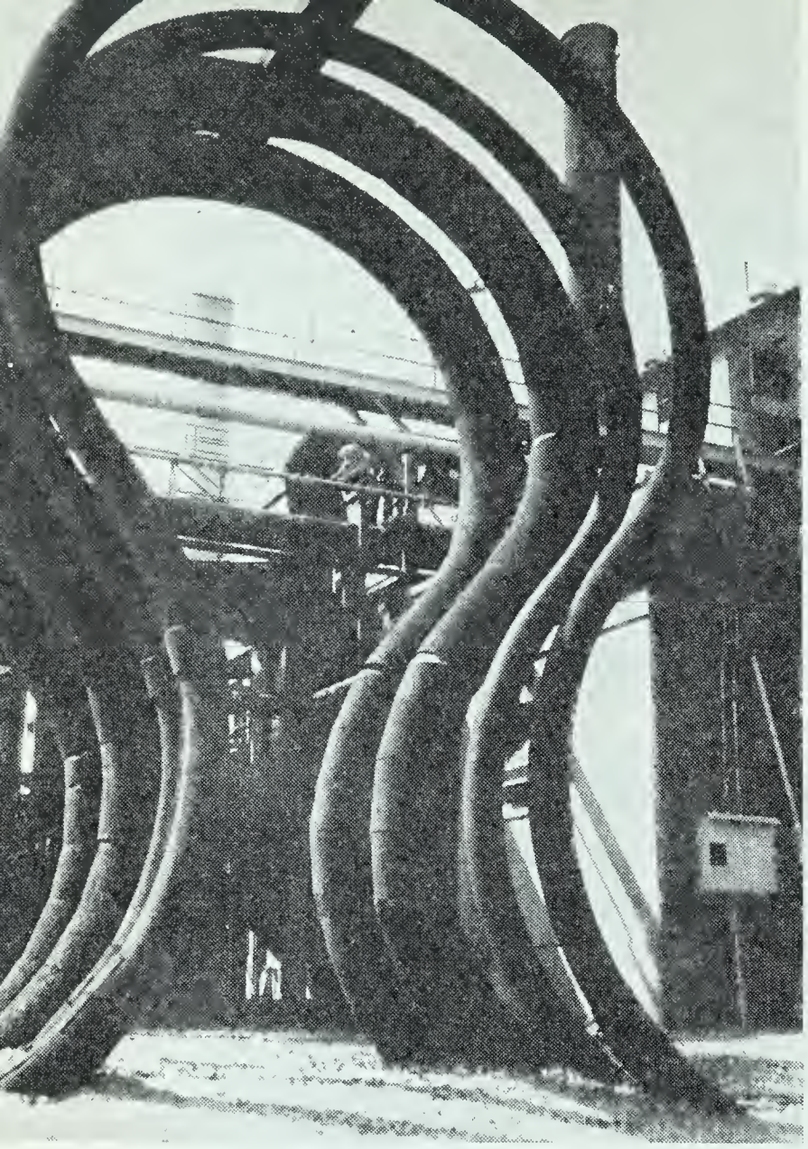
The same science ideas are seen at work in the operation of both the hot-air system and the hot-water system. Circulation in either type, unless forced mechanically, is explained by the difference in the weight of a cubic foot of the transfer medium when hot and when cold. The fact of this difference creates no mystery because of our everyday experience with the tendency of materials to expand when heated and to contract when cooled. In this tendency is also found the reason why an expansion tank is included in the hot-water system. But for this safety device, the pipes, radiators, or boiler would burst if the system were filled with cold water and then heated.

The expansion of the water in the hot-water system may be taken care of by means of an open expansion tank placed above the highest radiator or by a closed one in the basement. The former type has an overflow pipe, while the latter contains a cushion of air. The cushion of air is effective because gases, unlike liquids, are easily compressed into smaller volumes.

A more recent development is a hot-water system with forced circulation. A pump speeds the flow of water and makes possible the use of smaller pipes and radiators. Obviously a closed-type expansion tank is necessary in this system. While there is a reduction in fuel cost, there is also some added expense for power to operate the pump.

In general, hot-water systems are slow in heating, and the radiators and pipes are subject to freezing and bursting if unattended during severe winter weather, but the evenness of temperature which they maintain is a strong point in their favor.

The expansion of gases, liquids, and solids is one of the phenomena which man formerly had great difficulty in explaining. The recognition of such a problem and its clear definition constitute the first step towards its solution by the scientific method.



Courtesy American Petroleum Institute

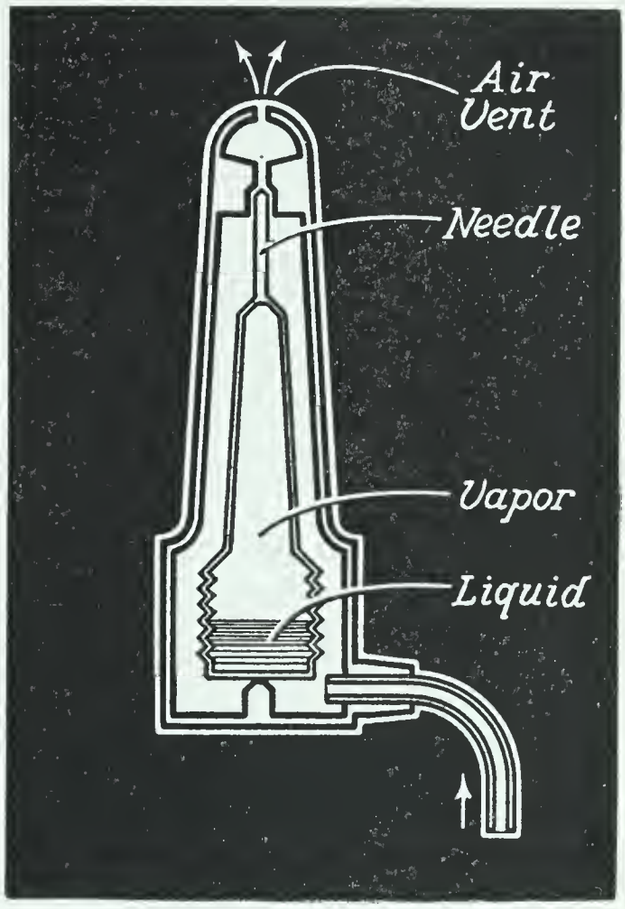
These loops in the pipes at a petroleum refinery take care of the expansion or contraction caused by changes of temperature in the material carried by the pipes.

After untiring observation, experimentation, generalizing, and checking, scientists are agreed that matter is composed of tiny, moving particles which they have named "molecules." Molecular motion is less in solids than in liquids, and less in liquids than in gases. Heat energy is believed to be the cause of the motion of molecules. Application of heat, therefore, speeds up molecular activity, while the removal of heat does just the opposite. As the temperature is raised, each little molecule needs more space to move in than when the temperature was lower, and it gets this extra space by pushing its neighbors aside as it bombards them in its random movements. Since all the molecules of a given quantity of matter do likewise, more space is taken up by the bulk of matter of which they are a part, and we say that the material has expanded. Taking heat away slows down the molecules, and there is a corresponding contraction in the volume of the material which they comprise. It is wrong to ascribe the expansion or contraction of matter to a change in the size of the individual molecules.

Although most molecules are too small to be seen with the most powerful microscopes, scientists have no doubt as to their reality. You will see why this is so as, from time to time, further evidence of the existence of molecules is presented.

In steam-heating systems, a boiler around the fire chamber of the furnace is kept partly filled with water. Since steam occupies about 1,700 times as much space as an equal weight of water, pressure is created as steam is generated. The inherent tendency of heated steam to expand forces it through the pipes and into the radiators. A return pipe from the radiators to the boiler is not

necessary because of the corresponding shrinkage in volume as the steam condenses to the liquid state. The water returns by gravity to the boiler through the same pipes which distribute the steam. Notice that neither gravity nor a mechanical device is depended upon for the distribution of the heated material within this system.



Explain how this air valve works.

More than five times as much heat is required to change water at the boiling point into steam at the same temperature as is required to heat the same quantity of water from the freezing point to the boiling point. When steam later condenses, the same large quantity of heat energy is liberated. This fact accounts for the great amount of heat furnished by steam-filled radiators. The same fact explains why considerable time is required to generate steam pressure even after the water in the boiler has reached its boiling point.

An examination of the air valve found on a steam radiator discloses several of the same principles as are found at work in the heating system as a whole. Water ordinarily contains some dissolved air which is expelled when the liquid is heated and later changed into steam. Each radiator is equipped with an air valve to permit the escape of this air and also of any other air that may be within the system. Since air occupies space, its presence in the radiators would tend to block the entrance of steam. When an air valve is provided, however, pressure of the inrushing steam easily forces the air to the exterior of the radiator. When the air has been expelled through the valve opening, hot steam enters the device and vaporizes a liquid within the float. The resulting pressure causes the float to expand and raise the needle, thus closing the valve. In this way, the escape of steam is largely prevented.

The most common complaint heard where the steam system is

used is that it is difficult to get uniform heating. Radiators heat very rapidly when steam enters and cool very quickly when there is no steam pressure. Considerable fluctuation in the rate of heating and cooling of the radiators in various parts of the living quarters is common, except where the system has been very carefully designed and installed. In addition, there is the previously mentioned lag in heating due to the fact that the water in the boiler must be brought to its normal boiling point and kept there for some time before steam pressure is developed. However, this disadvantage is overcome to a large extent in the vacuum-vapor system.

Vapor systems are essentially steam systems which have been modified in an effort to retain the advantages and eliminate the disadvantages. A return pipe from the radiator to the boiler has been added. To this line is attached a pump for withdrawing air from the system, thus reducing the pressure within. Under reduced pressure, water begins to boil at lower temperatures and changes to vapor more rapidly than at higher pressures. Somewhat lower radiator temperatures and slightly less transfer of heat per pound of vapor result, but more uniform temperatures are maintained with greater ease than in the one-pipe steam system. An added advantage of the vapor system is a lower operating cost with no decrease in heating efficiency.

• PREVENTING HEAT TRANSFER

Heat losses mean dollar losses. The purpose of a heating system is to transfer heat from a combustion chamber to various parts of a building and to distribute it as uniformly as possible. There is no intention of "heating the great out-of-doors." Yet the latter is precisely what occurs to a greater or lesser degree in all cases. Loss of heat to the outside of the building means that more heat must be supplied to maintain the desired inside temperature, thus resulting in greater fuel consumption and, consequently, increased cost. Adequate adjustment to this problem necessitates (1) knowledge of the more common ways in which heat is lost to the outside of a building; (2) application of our knowledge of conduction, convection, and radiation to prevent undesirable heat transfer.

Estimates of the U. S. Department of Commerce attribute heat losses to the following causes: 50 per cent through the walls and roof; 25 per cent through the doors and windows; 25 per cent through infiltration of cold air around doors, windows, and other sources.

These facts point to the conclusion that the surest way to conserve heat and thereby reduce fuel costs is to insulate. There is no doubt that insulation when properly applied to any house, old or new, will reduce the annual fuel bill. Furthermore, when applied to a new house, it makes possible the installation of a smaller and less costly heating system. The actual value in dollars and cents of the fuel saved by the use of insulation will depend upon the cost of the fuel, the severity of the weather, the kind and amount of insulation used, and such characteristics as the size of the house, architectural design, and type of construction.

Doors and windows are prime sources of heat losses. They might very well be the place to begin the attack in attempting to save fuel, especially in localities where there are severe winters. Heat passes out through the glass by conduction and radiation, and more cold air than is needed for ventilation seeps in through cracks and other openings around poorly fitted doors and windows. The chief methods of preventing heat losses at doors and windows are the use of storm doors, storm windows, and weather stripping.

Some realization of the value of storm sashes may be gained from the fact that their use has resulted in fuel savings up to 30 per cent during weather when the outside temperature was zero. This is possible because the "dead-air" space between the storm sash and the house window is a poor conductor and heat transfer is greatly retarded. It is essential, of course, that storm sashes fit tightly if they are to be fully effective. If cold air can still enter the space between the storm sashes and the house windows, strong convection currents may result and the value of this method of insulation will be greatly decreased. In addition to reducing heat losses, properly fitted storm sashes eliminate almost completely the soot and dirt which usually sift in through cracks around the windows. Since the surface temperature of the glass area exposed to the room is higher than it would be if the storm sashes were not used, it is possible to maintain a higher moisture content in the air of the room without condensation, or "sweating," occurring on the windows. Because of this higher temperature, downdrafts at the windows are also greatly reduced. This results in an increased temperature in the "living zone" of the room, especially near the floor. Thus it is evident that the use of storm sashes can be advantageous from the standpoints of health, comfort, and cleanliness, as well as with regard to heat conservation.

Doors and windows alike can be weather-stripped to prevent





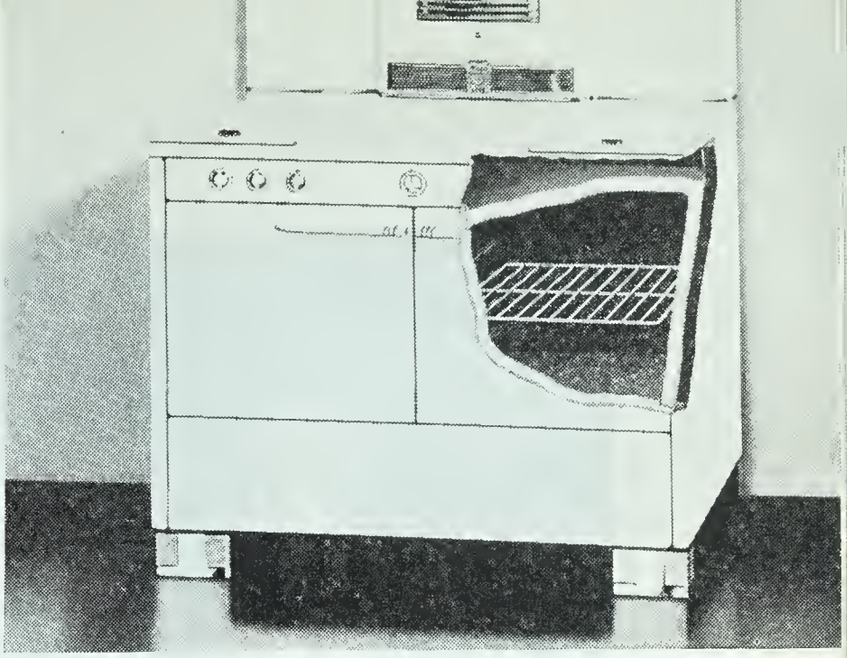
Courtesy Johns-Manville Company

These are two methods of applying insulation to homes and other structures. Which method is better suited for applying insulation to existing structures?

excessive leakage of cold air. Metal weather stripping applied by a competent workman will prove most effective, but even an amateur can install the cheapest fabric type with profitable results. The actual value of the fuel saved will depend, of course, on how well the job is done, the linear footage of weather stripping applied, and the amount of looseness around the doors and windows before the installation. Air leaks around the frames of doors and windows can be stopped by sealing with a calking compound. When cold-air leakage is reduced, drafts are reduced; thus it is evident that weather stripping contributes to the comfort of the occupants of the building and probably to their health as well.

Heat losses through the walls and roof of a house are also reduced by the use of insulation materials. Several types are available, and any chosen kind can be used to good advantage in the construction of a new house. For older houses, however, not very many can be used.

Cellulose products, various rocklike minerals, spun glass, and a few other materials are commonly used in the manufacture of insulation products. They may be fabricated in the form of large sheets, comparable to wall board, which can be fastened directly to the studding, or in "blankets," which can be cut to size and fitted in between the joists and studding. Still another form is the loose material, generally called "pellets" and "wool," examples of which are glass wool, rock wool, mineral wool, and "puffed mica." In many respects, the rock wool and puffed mica are easiest to apply, especially to houses already built, for they can be packed in place by hand or can be blown in between the walls and floors by means of compressed air.



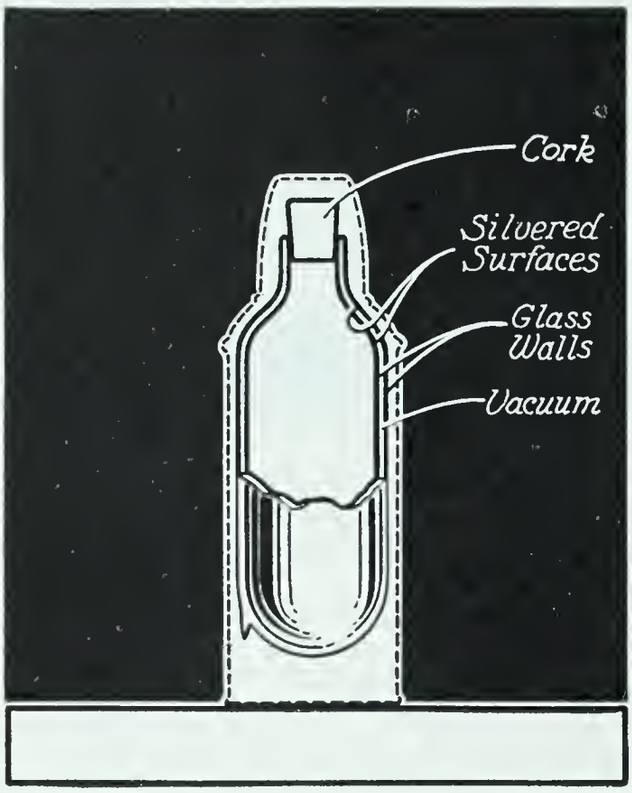
Courtesy American Stove Company

What advantages can the manufacturer justly claim for a well-insulated stove oven?

The minimum requirements for an insulation material should be that it is verminproof and fire-resistant. Insulation board and blankets manufactured from plant materials do not meet these requirements unless they are chemically treated. On the other hand, various types of mineral wool are strongly recommended by competent builders, because such materials more than satisfy the minimum requirements. They are fireproof and verminproof and are nonconductors of electricity; moreover, "sweating" and condensation of moisture between the walls—the bugaboo of all insulation materials—is less damaging to mineral than to cellulose materials.

All insulation materials operate on the same basic science idea; namely, the control of heat transfer by the control of conduction, convection, and radiation. All of the materials mentioned as being useful for insulation purposes are very poor conductors of heat. They are more or less porous and enclose tiny pockets of air, which constitute "dead-air space." In addition, filling the space between the walls and floors with loose insulation materials prevents convection currents, one of the important causes of heat losses. At least one manufacturer has devised an insulation product intended to prevent radiation. It consists of gypsum board covered on one surface with thin aluminum foil. The bright metallic surface reflects radiant heat in the same way that a mirror reflects light, thus keeping winter heat in and summer heat out. Other types of insulation also keep out summer heat to a large extent, thus bringing about reduced house temperatures during that season of the year. This is an added benefit of insulation that does not appear in the reduction of fuel bills.

Man's adjustments to the problem of keeping heat where he wants it are not restricted to the insulation of buildings. He likewise finds it desirable to prevent heat transfer in the case of refrigerators and cold-storage rooms; stove ovens; fireless cookers; vacuum bottles; steam boilers and hot-water tanks; pipes for conveying steam or hot water; and in numerous other instances. In all cases, the same principles of insulation are employed, and a var-



How does the vacuum bottle retard heat transfer?

iety of materials too extensive to enumerate are used. The vacuum bottle involves an interesting method of insulation, in which a double-walled glass vessel is used. The air is pumped out of the space between the two walls, and the entire surface is silvered like a mirror. The vacuum between the two walls makes heat transfer by conduction and convection practically impossible, and the shiny surface reflects radiant heat. The effectiveness of bottles and jugs making use of this principle is well known.

• CONTROLLING HEAT CONTENT

A few simple science ideas underlie all of the methods used by man to refrigerate foods in order to retard decay. Perhaps we can best develop an understanding of these principles by first asking, "Is there anything to which you can add heat without making it hotter, or from which you can remove heat without making it colder?" Impossible as it may seem, the answer on both points is "Yes!" Heat applied to water boiling in an open vessel does not make the water any hotter, and, likewise, the removal of heat from water at the freezing point does not make it any colder. True, the boiling water changes into steam, and the water at the freezing point becomes ice, but neither undergoes any change in temperature during this change of state.

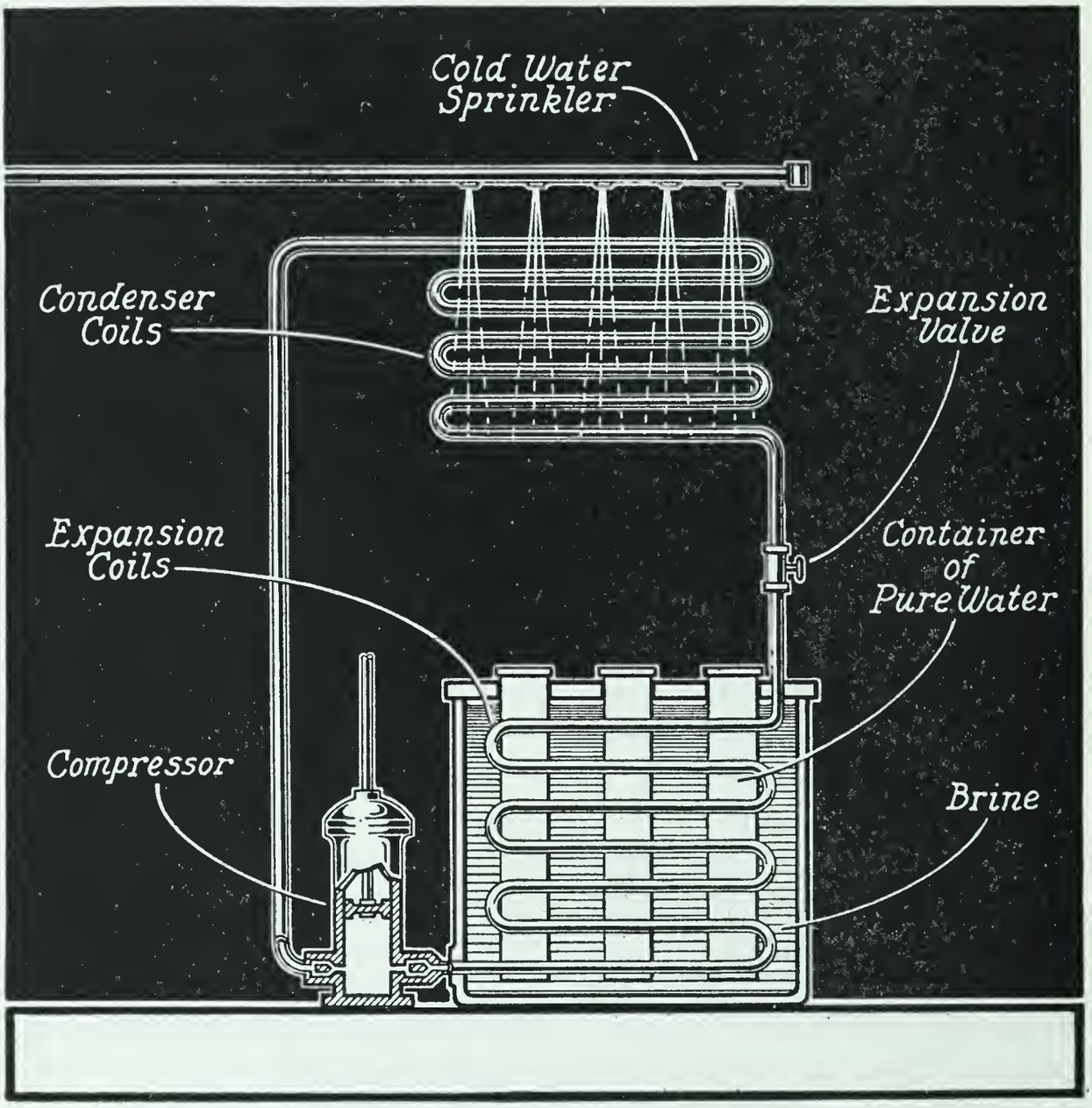
As you know, there are three physical states of matter—the solid, liquid, and gaseous. Although most of the water that we see exists in the liquid state, we are also acquainted with it in the form of ice (a solid) and in the form of steam (a gas). Nearly all other materials can also exist in all three physical states. Iron, mercury, carbon dioxide, alcohol, gasoline, and paraffin are a few such materials. We call solidified carbon-dioxide gas "dry ice," and perhaps you have had some acquaintance with liquid air. Like water, all these materials give off heat while changing from gas to liquid or from liquid to solid. When making the reverse

changes in state, they all absorb heat energy. Note particularly that an evaporating or a melting material takes from objects near it the heat necessary for the evaporating or melting. Hence we say that evaporation and melting are cooling processes—that is, so far as their surroundings are concerned. Melting ice cools the inside of an icebox and the food stored within it by robbing them of heat energy which continues the melting of the ice. Some people never realize that *cooling* really means *loss of heat*, and fewer still know about the large heat quantity given off or absorbed during a change of physical state.

Mechanical refrigerators are of two general types, but both types operate on the principle that evaporation is a cooling process. Electricity furnishes power to one type, while the other uses heat energy from some fuel, usually gas. Commercial plants for the manufacture of ice are similar in operation to electric refrigerators. In these ice plants a pump compresses ammonia gas which is enclosed within a system of pipes. The heat given off by the gas during its compression is removed by cold water sprayed upon the pipes. Ammonia gas is used because compressing and cooling readily cause it to condense and become liquid. The liquid ammonia is then forced by the pressure into another set of pipes which is surrounded by ordinary salt solution, or brine. Here the liquid ammonia evaporates and cools the brine so much that containers of fresh water lowered into it are frozen. The brine does not freeze because the dissolved salt lowers the freezing point of the solution below that of fresh water.

In electric refrigerators the cooling is accomplished in the same manner. An electric motor operates the compression pump, and air set in motion by a fan, or simply by convection, is used instead of a spray of water to cool the compressed gas. Some other gas, such as sulfur dioxide or dichloro-difluoromethane, commonly called "Freon," is substituted for ammonia, because it liquefies more readily than ammonia. The Freon also has the advantages of not being inflammable, poisonous, or irritating. The possibility always exists that some of the gas may escape into the room through a break in the system.

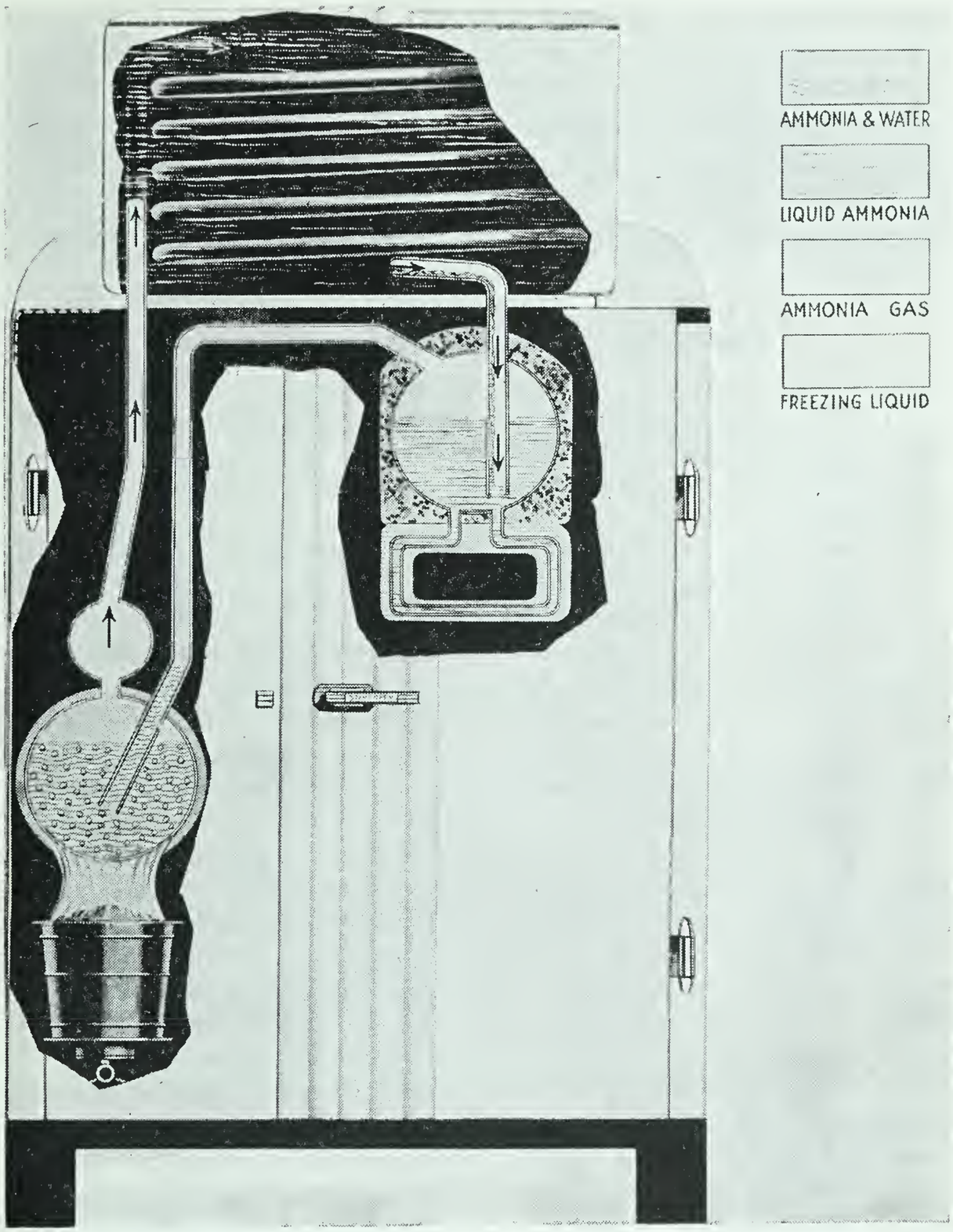
After liquefaction and cooling, the refrigerant passes through a pipe to the interior of the refrigerator where it evaporates within the cooling unit located near the top of the compartment. The heat needed to promote the change from liquid to gas comes from the walls of the compartment, from the air within the refrigerator, and from the stored food and its containers. As a result,



Trace the steps in the manufacture of ice and explain the science principles involved.

the temperature falls to the point where bacteria can no longer thrive and multiply rapidly. A thermostat within the refrigerator controls the action of the electric motor and hence the amount of cooling.

The operation of the gas refrigerator is more complicated than that of electric refrigerators. The cooling is not rapid but the gas refrigerator has no motor and is free of noise. Heat from a gas flame causes ammonia gas to escape from a strong solution of ammonia and the resulting pressure plus cooling by water cause the ammonia to liquefy. The cooling of the refrigerating compartment results from the later evaporation of this liquid ammonia sometimes in the presence of hydrogen gas, which is also enclosed



Courtesy Perfection Stove Company

This machine makes ice from oil heat by applying the principle—evaporation is a cooling process. How does it work?

within the cooling unit. After the evaporation and cooling, the ammonia and hydrogen pass through a tube of water in which the ammonia dissolves and returns to the heating unit. Hydrogen gas does not dissolve in water to any great extent, and it remains in

the cooling unit. Strangely enough, burning more fuel causes greater cooling inside the refrigerator.

The efficiency of any refrigerator depends to a considerable extent upon proper insulation to keep room heat from getting into it. The first cost of mechanical refrigerators may be rather high, but they pay for themselves in proper food preservation. Their operation costs are usually lower than those for iceboxes.

Exercises for Problem Study and Review

1. State one fact about each of the three methods of heat transfer that does not apply to the other two.
2. Why does convection ordinarily contribute to ventilation as well as to heating?
3. How does the pipeless warm-air furnace work? What are its advantages and disadvantages?
4. How does the piped warm-air furnace differ from the pipeless furnace? Why is it unnecessary to make provision for bringing in outdoor air for ventilation? What are the advantages and disadvantages of this type of heating system?
5. When radiator systems are used, where should the radiators be placed? How does painting radiators affect their efficiency? What kind of paint would you advise for use on radiators?
6. What are the chief differences in construction between the piped warm-air heating system and the hot-water system? What are the advantages and disadvantages of the hot-water system?
7. Why is a return pipe from the radiators to the boiler not necessary in steam-heating systems? What causes the heated material to circulate in the steam-heating system? In warm-air systems? In hot-water systems?
8. Which furnishes more heat for each pound of heated material delivered to the radiator, the hot-water system or the steam-heating system? Explain.
9. Why are radiators of steam-heating systems equipped with air valves? How do they work?
10. List the advantages and disadvantages of the steam-heating system.
11. How does the vacuum-vapor system largely overcome one of the chief disadvantages of the steam-heating system? Is there any additional advantage in the vacuum-vapor system?
12. In what places do the big heat losses occur in uninsulated houses? Why is it desirable to reduce these losses? How can it be done?
13. Explain why storm sashes are so effective in reducing heat losses through windows of houses. Which big loss does weather stripping

reduce? How can heat losses through the walls and roof of a house be reduced?

14. In what forms is insulation material sold? Of what materials is it commonly made? Which types are easiest to apply to houses already built? What are the minimum requirements for an insulation material other than that it retard or prevent heat flow? Which insulation materials best satisfy these requirements?

15. What basic science idea underlies the operation of all insulation materials? Name two characteristics common to the various insulation materials. Is house insulation advantageous in the summertime? Explain.

16. How is each kind of heat transfer retarded in the vacuum bottle? Use a labeled diagram of a vacuum bottle to supplement your answer.

17. Explain how heat can be added to or removed from water without making it hotter or colder. How do we make use of these facts?

18. Enumerate the science principles involved in the electrical refrigerator and explain how they are applied.

19. Explain how a gas refrigerator produces cold from heat.

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. Outline the steps in scientific problem solving, and decide whether this method was followed in the development of the true explanation for burning. Explain your answer.

2. What scientific attitudes does a study of Lavoisier's work reveal?

3. A draft of air is needed for a fire to burn, but if a strong gust of wind comes along it may extinguish a fire. What hypotheses can you suggest to account for these facts?

4. What do you think of proposals to curtail, or even to prohibit, the use of fuel oil and oil burners for domestic heating?

5. Two identical aluminum vessels are partly filled, one with water and the other with an equal weight of lubricating oil. They are placed over a stove adjusted so that they both receive heat at the same rate. How will the rates at which their temperatures increase compare? Why?

6. The heat capacity of water is the basis of the definition of the *calorie*—that is, *the quantity of heat required to raise the temperature of one gram of water one degree centigrade.* The heat capacity of lead compared to water is 0.03; of iron, 0.119; and of aluminum, 0.22. Enough heat is added to 1,500 grams of water to change its temperature from 30° to 90° centigrade. What would be the final temperatures of equal weights of iron, lead, and aluminum if this same quantity of heat were added to each at the same initial temperature?

7. A housewife bought 100 pounds of ice and had it put into her

icebox. Then she carefully covered it with newspaper, explaining, "This newspaper keeps the cold in and prevents the ice from melting, so it lasts much longer." Was she acting in terms of scientific facts? Was she being economical? Explain fully.

8. Why is gasoline vaporized before burned in an engine? Why is it dangerous to use a match to see how much gasoline there is in the tank of an automobile? Compare the danger when the tank is full and when it is nearly empty.

9. Distinguish between chemical change and physical change. To which class does burning belong? Why? Give several more examples of each.

10. Why is it a good thing to lower a lighted lantern into a deep well before entering it to make repairs?

11. How can such devices as electric toasters and flatirons cause fires when no flame is present?

12. Why is it unnecessary to have a circulating pump in a hot-water system?

13. Is smoke pushed or pulled up a chimney? Explain.

14. What is heat? What is cold?

15. If a house is constructed to conserve heat in winter, will it not also be warmer in summer? Explain.

16. How would you regulate the windows and doors of an insulated house during the daytime and at night to keep the house as cool as possible in summer?

17. Every pure substance has a definite melting point. Is butter such a substance? Would it be as useful if the opposite were true?

18. The United States has about 50 per cent of the world's known coal reserves, but only about 6 per cent of the world's population. What possible future problems or consequences based on these facts would you predict?

19. Explain the science principles that are employed in extinguishing the following types of fire: (1) a burning house; (2) a burning automobile; (3) a burning forest; (4) a burning oil storage tank; (5) a person's burning clothing; (6) a burning electric motor.

UNIT WORD LIST

kindling temperature
destructive distillation
by-product
British thermal unit
hydrocarbon
vaporize
condense
liquefy
inflammable
calorie
heat capacity
calorimeter
conduction
convection
radiation
molecule

distillation
cracking
volatile
synthesis
octane number
oxidation
spontaneous combustion
temperature
expansion
contraction
physical state
melting point
boiling point

INTERESTING THINGS TO DO

1. Prepare a collection of advertisements for gasoline and show how they make use of technical or scientific facts about which the consumer ought to know.

2. Obtain the prices of anthracite and bituminous coal, coke, fuel oil, and gas in your locality; find out the calorific value of each fuel. Assume that ten tons of anthracite coal are consumed in heating a house during one season. Calculate the amount of fuel needed and the total cost of heating the house by the use of each of these five different fuels. Summarize your findings in the form of a chart or graph. Should any factors other than fuel cost be taken into account in comparing your figures?

3. Make a list of several places in the construction of a house where fire-resistant materials can be substituted for very combustible ones. Make a list of the fire-resistant materials you would recommend in place of the combustible ones generally used.

4. Visit the fire department in your community and find out the causes of, and damages resulting from, some recent destructive local fires. How might they have been prevented?

5. Shall I heat my home by the use of coal, oil, or gas? Prepare a collection of advertisements and selected facts and figures on this question.

6. Shall I purchase a gas range or an electric stove for use in my kitchen? Collect advertisements and facts and figures on this question.

7. How shall I select a new gas range for my kitchen? Secure advertisements, visit a local dealer and investigate the various claims made, and summarize your findings.

8. Prepare a wall chart for your classroom on "What Comes from Coal."

9. Make a wall chart for your classroom on "What Comes from Petroleum."

10. Prepare a display of as many chemical elements as you can obtain.

11. Posters on the following topics would be interesting to prepare and would have great educational value: (1) the means of saving fuel in heating a home; (2) the means of saving gas in the home; (3) a draw-

ing and explanation of the soda-acid fire extinguisher; (4) a concise list of fire-prevention and fire safety rules for the home.

12. Investigate what literature the United States Government Printing Office has pertaining to topics within the unit. Write to the Superintendent of Documents for copies and make them available for class reference.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Solar heat engines.
2. Chemical refining of gasoline.
3. A summary of any local or state laws or regulations pertaining to the sale of gasoline in your locality.
4. How oil wells are drilled and how oil is pumped.
5. How buildings are made fire resistant.
6. How fabrics are flameproofed.
7. History of the thermometer.
8. History of matches.
9. Types of thermometers and their uses.
10. Fuels of the future.
11. How to increase the efficiency of operation of a refrigerator.
12. The researches, discoveries, and inventions of eminent scientists whose work relates to topics within this unit—Priestley, Lavoisier, Rumford, Joule, Davy, and others.
13. Sources of energy not traceable to the sun.

INTERESTING BOOKS TO READ

Gilfillan, Lauren W., *I Went to Pit College.* The Viking Press, New York, 1934. The story of a girl's experience among the coal miners and their families.

Greenwood, Ernest, *Prometheus, U. S. A.* Harper and Brothers, New York, 1929. A very readable story of fire and the even more important story of the development and use of different types of fuel. Economic and social aspects of the fuel problem are discussed.

Lemon, Harvey B., *From Galileo to Cosmic Rays.* University of Chicago Press, Chicago, 1935. A survey of physics done in unique style and with interesting illustrations. Somewhat advanced. Excellent discussion of heat.

an Made "Hot" Lightning ars Things Up—and Burns 'Em

ARON, Pa., May 8.—Man-made ning, with the same destruc- fire-producing qualities as that uced by nature, made its formal to the world today in a spec- ar demonstration at the Sharon

The sand was scattered, the metal sheet was scorched and dented, the transmission pole was splintered. But none of the targets was set afire.

Then the hot lightning was given a chance. A haystack was fired, the sand was fused into exact replicas

ome Drivers Partly Crazy

Psychiatric Association Is Told—Violators in Detroit Found Mentally Ill

ICAGO (AP)—The belief of strians that automobile drivers

is to put the mind in reverse, re- orient it from the time it began

lds Static Spark used Explosion tal to Patient

Woman's Trachea Ruptured by Blast, Doctor Believes

static spark inside a rubber iner of cyclopropane gas may caused the explosion which re- yesterday in the death in the

UNIT TWO POWER AND MACHINES

COULEE DAM BEGINS PRODUCING ENERGY

Thousands Throng Project as First Generator Starts Two Years Ahead of Schedule

INDIANS AT COLORFUL FETE

President in Message Stresses Jobs Factor in Construction and Value to Defense

GRAND COULEE DAM, Wash., March 22—The Grand Coulee Dam turned over its first generator at 1:25 P. M. today, two years ahead of schedule, and sent 10,000 of an ultimate capacity of 1,974,000 kilowatts, or 2,475,000 horsepower, into the network of transmission

Export Airlines Plans Service to Ireland

SUN LAMP BY TUB COSTS LIFE OF BRIDE

Victim Believed Shocked and Drowned While in Bath

The habit of taking an artificial sun bath by means of a health lamp

Chicago Has Blackout Too —Balky Fuse Is to Blame

Thousands of commuters pouring their trains, striking more match

ost Traffic cidents Laid Pedestrians

ege Girls Start Air Transport Course

mphis.—A comprehensive e in aviation groundwork to int young women with the

Mile-an-Hour ver Has 10 Days Take His Time

At last a motorist has been

Finish Cherokee Dam Dec. 1, 4 Months Early

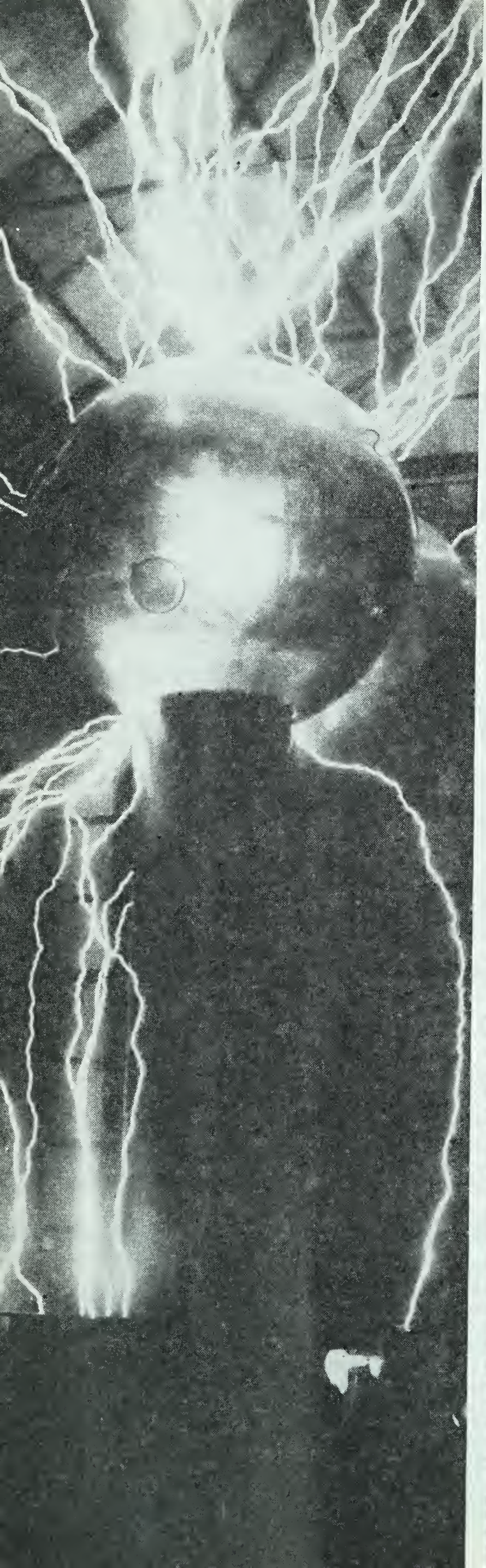
KNOXVILLE, Tenn., Nov. 28.—(AP)—The $30,500,000 Cherokee Dam, the Tennessee Valley Authority's newest hydroelectric project to increase power for national defense, will be completed December 1—four months ahead of schedule. The dam will hold back the waters of the Holston River a stream emptying into the headwaters of the Tennessee River in East Tennessee. It was authorized by Congress as a national defense power project sixteen months ago.

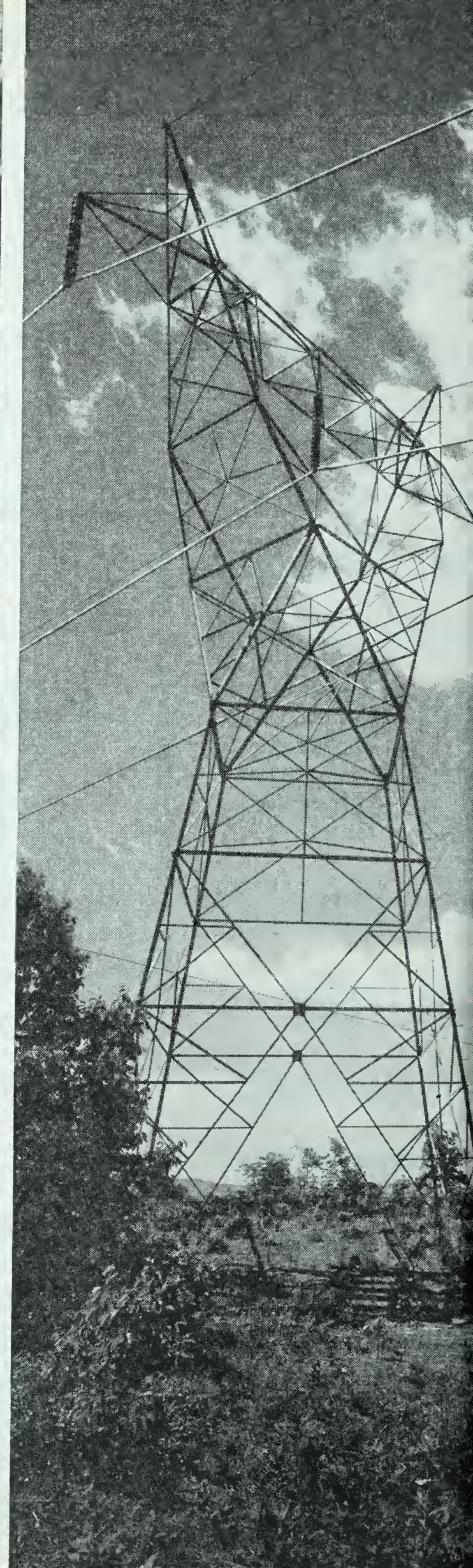
Electric Energy Output Increases 9.5 Per Cent

March Total 10,358,852,000 Kilowatt Hours

Power Output in Week Rebounds

The amount of electrical energy distributed by the electric light and power industry for the week ended November 29 rebounded 2.7 per cent to 3,293,415,000 kilowatt





Unit Two

POWER AND MACHINES

The present age is often called the machine age because of the mechanical devices man has developed to do his work. The machine has penetrated nearly every phase of modern life. Our factories hum as complex machines feed their products to seemingly endless assembly lines. In our homes, we simply snap a switch to put machines at work cleaning carpets, mixing foods, producing heat or cold, or washing clothes. Office workers write letters, make calculations, take dictation, and even do bookkeeping by means of machines. Today, there are enough automobiles in the United States to transport simultaneously every man, woman, and child —without crowding! Without doubt machines will become even more indispensable to the world of tomorrow.

Although the word "machine" is likely to call to mind something as complex as an automobile or a printing press, such a complex machine is really a combination of simple machines. There are six simple types of machines—the lever, the pulley, the wheel and axle, the inclined plane, the screw, and the wedge. Basically, a can opener, a screwdriver, or a shovel is just as truly a machine as is the automobile or printing press.

Because machines require power to drive them, man has had to find new sources of energy as the uses of machines have multiplied. Power from such sources as coal, oil, gas, and water is a necessity of modern civilization. Gasoline motors, Diesel engines, steam engines, and water wheels are among the devices commonly employed to develop power from these sources.

Electricity is really not a source of power, but rather a means of transferring power. Until a comparatively few years ago, the use of water power, for example, could not be extended far beyond the place where it was generated. Today, through the marvels of electricity, energy from a waterfall or river, as well as energy liberated by burning coal, oil, or gas, can be transported by wires to do useful work in cities 300 or more miles distant.

In this unit you will learn how man is at present solving the age-old problems of obtaining, controlling, transmitting, and using power.

Photos courtesy General Electric Company; Tennessee Valley Authority



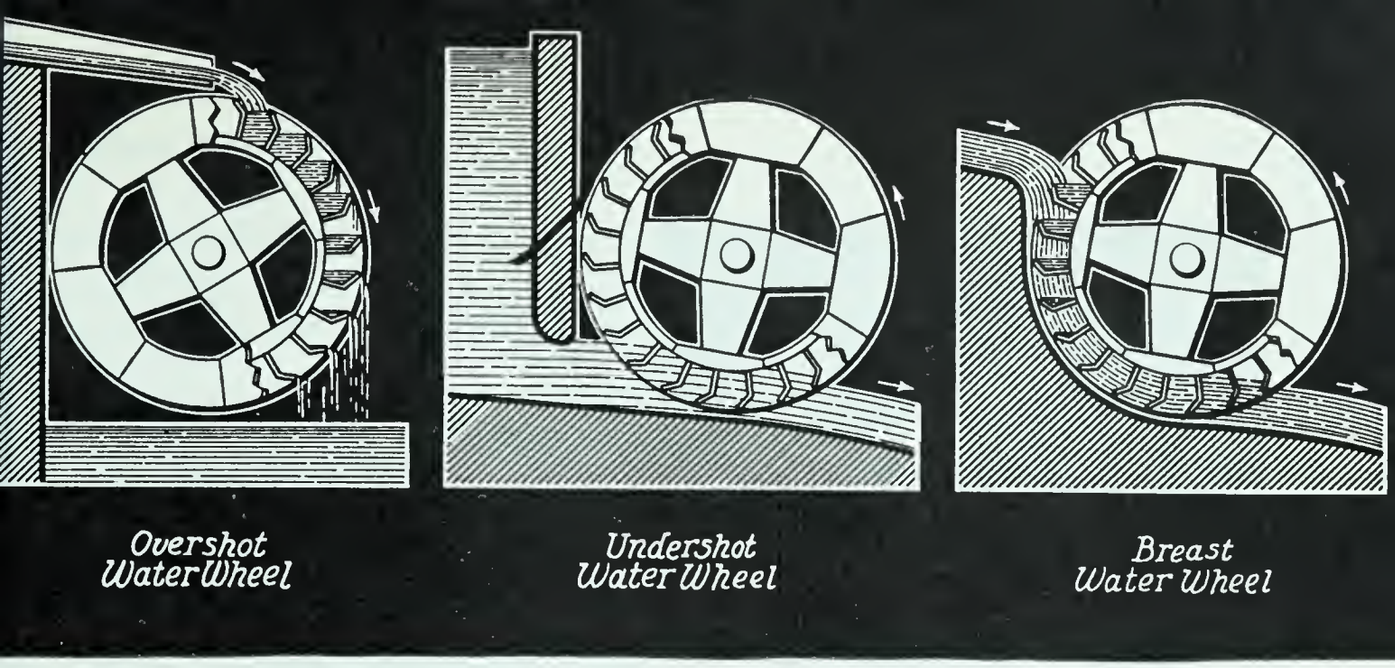
Problem 1: How does man obtain power?

• POWER FROM MUSCLES, WIND, AND WATER

Early man depended for power on muscles only. Although the human body is highly efficient, its capacity for doing work could not keep pace with man's ambitions. To reinforce his own weak muscles, he pressed into service such animals as the horse, ox, elephant, and camel. Until the middle of the eighteenth century, muscles continued to be the largest single source of power.

No one knows when wind and running water were first harnessed to lighten the strain on muscles. Pictures on Egyptian pottery show how sails were used on ships nearly six thousand years ago to add to the power developed by the muscles of the slaves manning the oars. Still another use for the wind was found when the windmill was built and put to work grinding grain sometime during the twelfth century in England. The Egyptians very early adapted water power to the operation of mills for grinding grain. Such mills did not possess the chief disadvantage of windmills—that of be-

Courtesy General Motors Corporation



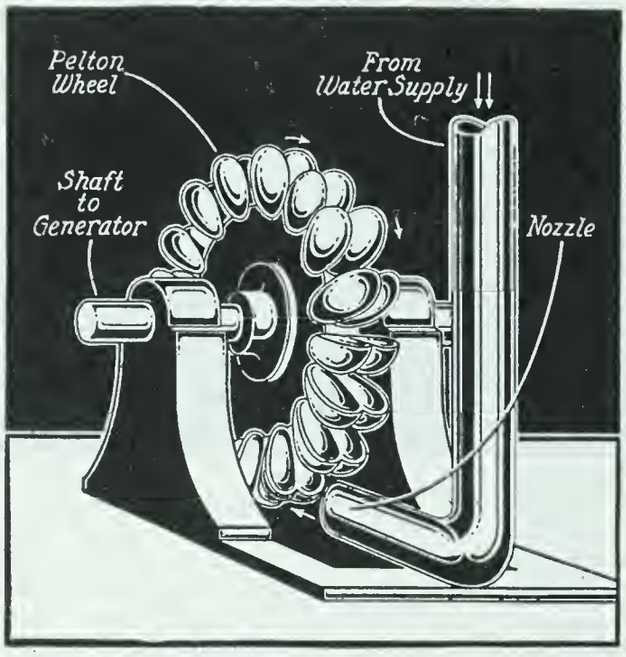
Water wheels capture the energy of moving water.

ing subject to the fickleness of the wind. Both wind and water-driven mills have continued in use down through the centuries. Today, however, they are largely supplanted by mills using more recently developed sources of power.

Windmills and water wheels harness the kinetic energy of wind and water. Energy is the capacity for doing work, and kinetic energy is the energy a thing has as a result of its *motion.* All energy is either kinetic or potential. Potential energy is the capacity for doing work which something has because of its *composition* or its *position.* For example, water in a reservoir which is located high in the mountains has a large quantity of stored energy. As this water rushes through pipes or in a stream to a town located in the valley below the mountains, its potential energy is gradually changed into kinetic energy. A stick of dynamite contains a vast amount of potential chemical energy which can do work when it is changed to kinetic energy through chemical action.

Man has used various types of water wheels to capture the kinetic energy of water and make it do work for him. Today we describe one type of water wheel as "undershot" and another type as "overshot." Examine the illustration and you will see the reasons for these names.

In 1884, Pelton, an American, built a water wheel to develop power where the "water head" is great. By water head is meant the vertical distance between its source and the place where the water is used. At Lake Tanay, Switzerland, a water head of 3,018 feet produces a velocity of approximately 200 miles an hour at the nozzle to which the water is piped. Here the stream is directed against the buckets on the rim of the Pelton wheel. The wheel receives up to 85 per cent of the water's kinetic energy and may be used to turn generators which transform this energy into electrical



The Pelton wheel is used where the "water head" is great.

energy. Pelton wheels have the advantage of being used successfully where the volume of water is not great.

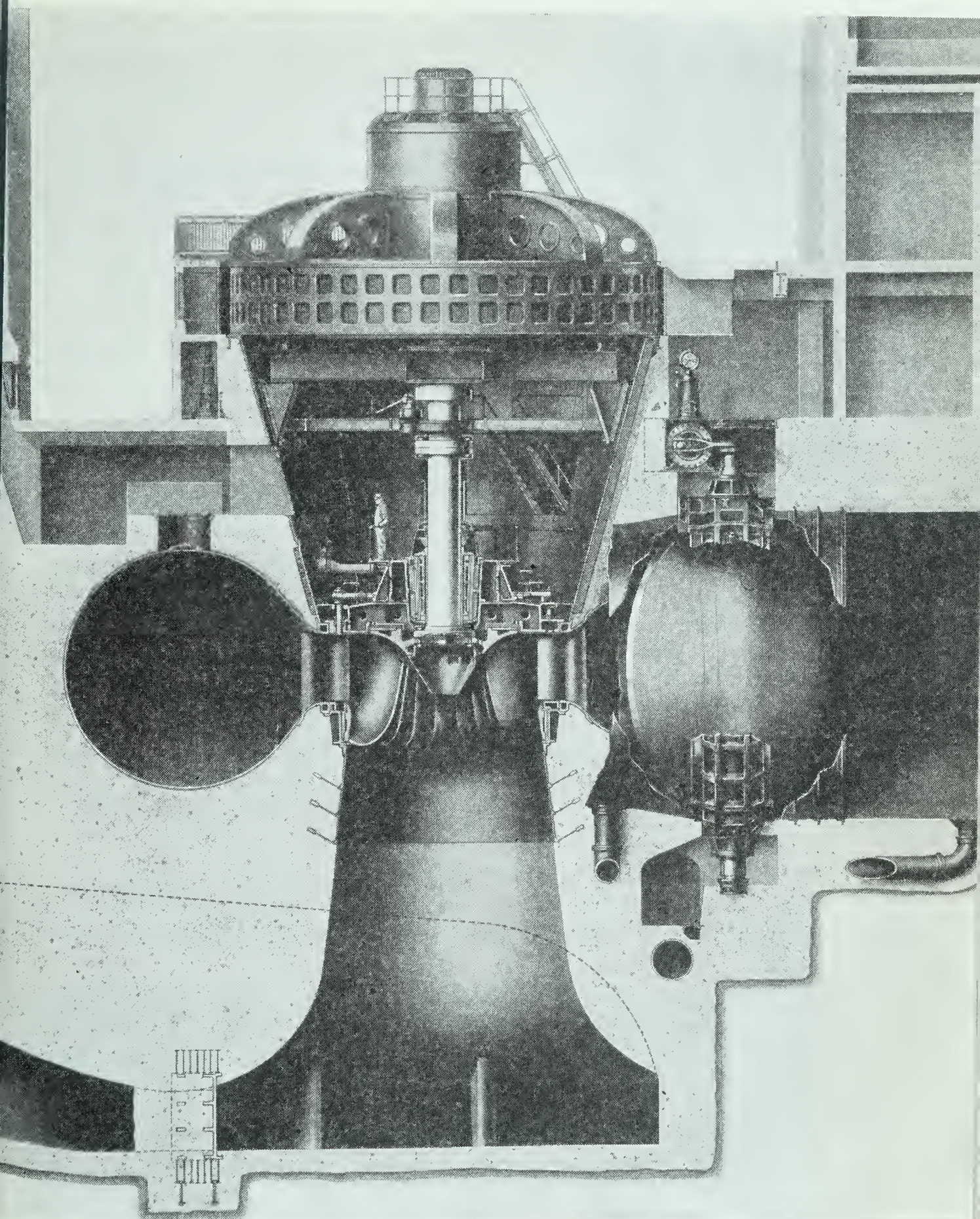
Where a large volume of water of less water head is available, the reaction turbine can be effectively used in the development of power. As the illustration on page 101 shows, the vanes of the rotor are set so that they would also change the direction of the stream of water if the rotor were not free to move. The water resists this change of direction and drives the rotor, which in turn is generally used to rotate a dynamo for the generation of electrical power.

According to calculations of engineers, about 240,000,000 horsepower could be developed from the flow of water (exclusive of tides) throughout the world. Only about one-eighth of this total has been developed up to the present time, nearly 40 per cent of this in the United States. It is estimated that even here, four times as much water power is lost in the unharnessed tides alone as is now developed from rivers and streams where turbines or other devices have been installed.

• FROM HEAT TO POWER

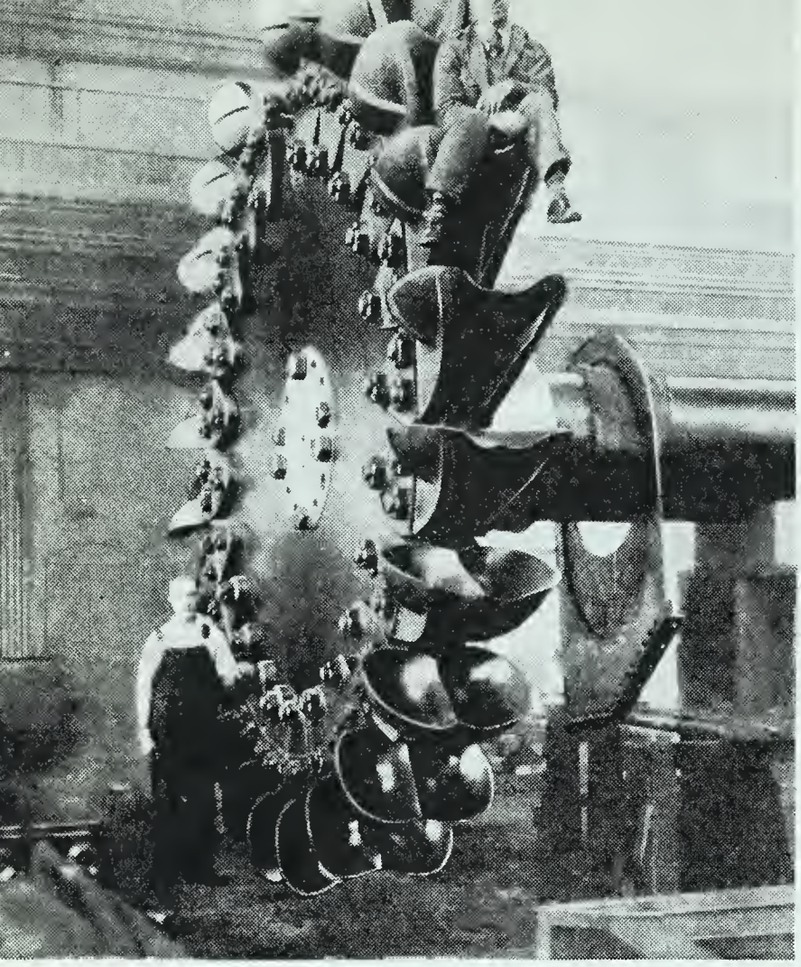
Watt turns heat into work. Some believe that no other man has had as great an influence on the world as James Watt, a Scotch inventor who, in the 1760's, invented the modern form of the steam engine. Of this much we can be certain: his invention has made possible the industrialized type of civilization found today in the enlightened parts of the world.

Steam for the engine is generated in boilers of two types: *the fire-tube boiler* and *the water-tube boiler.* In the locomotive, exhaust steam escaping through the smokestack produces a powerful draft which causes flames and hot gases from the firebox to rush through long tubes which are surrounded by water. The heat transfer may convert as much as twenty-five tons of water into



Courtesy Allis-Chalmers Manufacturing Company

This is a cross section of a 54,000 horse-power turbine. Notice the 27-foot diameter record-size butterfly valve for controlling the flow of water. This turbine operates at a speed of 82 r.p.m. under a normal head of 89 feet.



Courtesy Allis-Chalmers Manufacturing Company

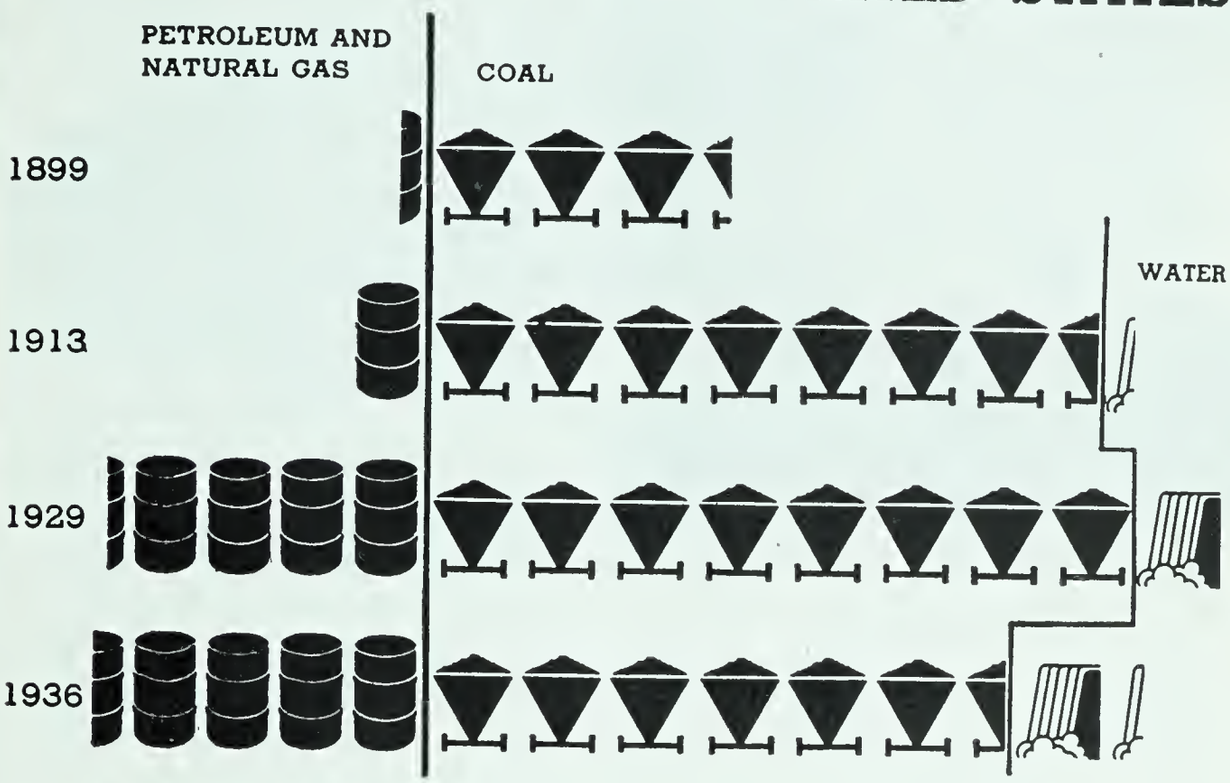
This is the bucket wheel for a 56,000-horsepower turbine. It operates on a 2,000-foot water head, so that the water passes over the bowl surfaces at about 120 miles per hour. At a speed of 375 r.p.m., each bucket passes through the jet about six times each second.

steam each hour when the locomotive is in operation. In the water-tube boiler, the flames and hot gases come in contact with the exterior of tubes filled with water as well as with other exterior parts of the water reservoir. This type of boiler is commonly used to supply the steam for stationary engines. Exhaust gases and exhaust steam are often used to preheat the water before it enters the boiler in order to save fuel and lessen operating costs.

The efficiency of boilers is sometimes increased by substituting mercury for water as the liquid used. If this is done, the vaporized liquid must be kept in a closed system so that it can be condensed and used again and again, because mercury is expensive and its vapors poisonous. Advantage is taken of the fact that the temperature of the mercury after condensing is so high that it can still be used as a source of heat for vaporizing water to produce steam. By using a combination of steam and mercury boilers with turbines, the power developed from each pound of coal consumed has been increased by more than 50 per cent above what it is when steam boilers alone are used.

The steam engine makes use of the force exerted by steam as it expands. Since water expands to about 1,700 times its original volume as it changes into steam, pressure develops in the boiler as heat from the burning fuel causes vaporization. As you can see in the diagram of the steam engine, the steam is piped from the boiler to the steam chest above the cylinder. The two openings in the cylinder are alternately connected with the steam chest and the exhaust by the slide valve. When one end of the cylinder is thus connected with the steam chest, steam rushes into this end of the cylinder and by its expansion drives the piston to the other end. The moving piston pushes the spent steam of the pre-

SOURCES OF ENERGY IN THE UNITED STATES

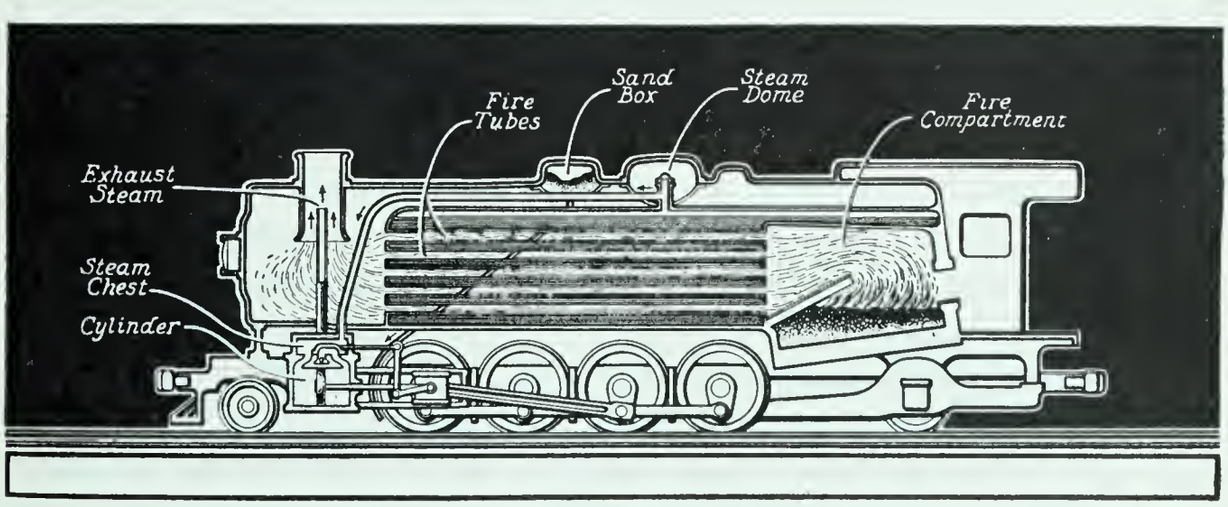


Each symbol represents 2000 trillion B. T. U.

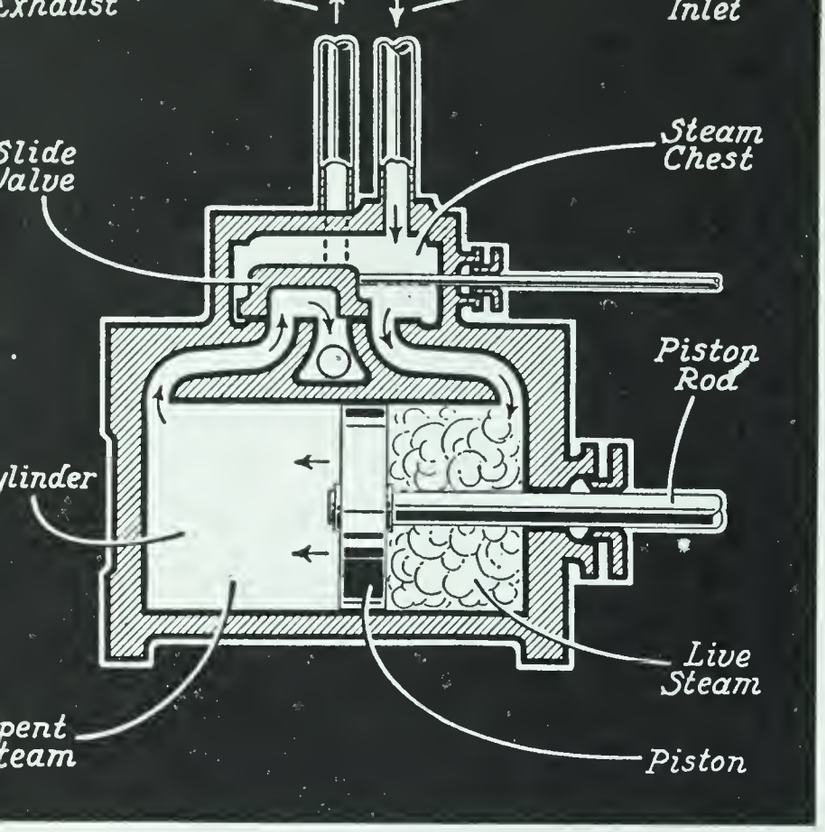
PICTORIAL STATISTICS, INC.

Courtesy American Petroleum Institute

vious stroke out of the cylinder through the opening at the other end of the cylinder which is now connected to the exhaust. As this stroke is completed, the end to which the piston has just moved is suddenly connected by the sliding valve to the steam chest and the other end to the exhaust. The piston is driven back to its former position and the spent steam of the previous stroke is expelled from the cylinder as before. Thus the piston is driven



How many science principles and ideas can you identify in the steam locomotive?



Study this diagram and the text to find out how the steam engine develops power from heat.

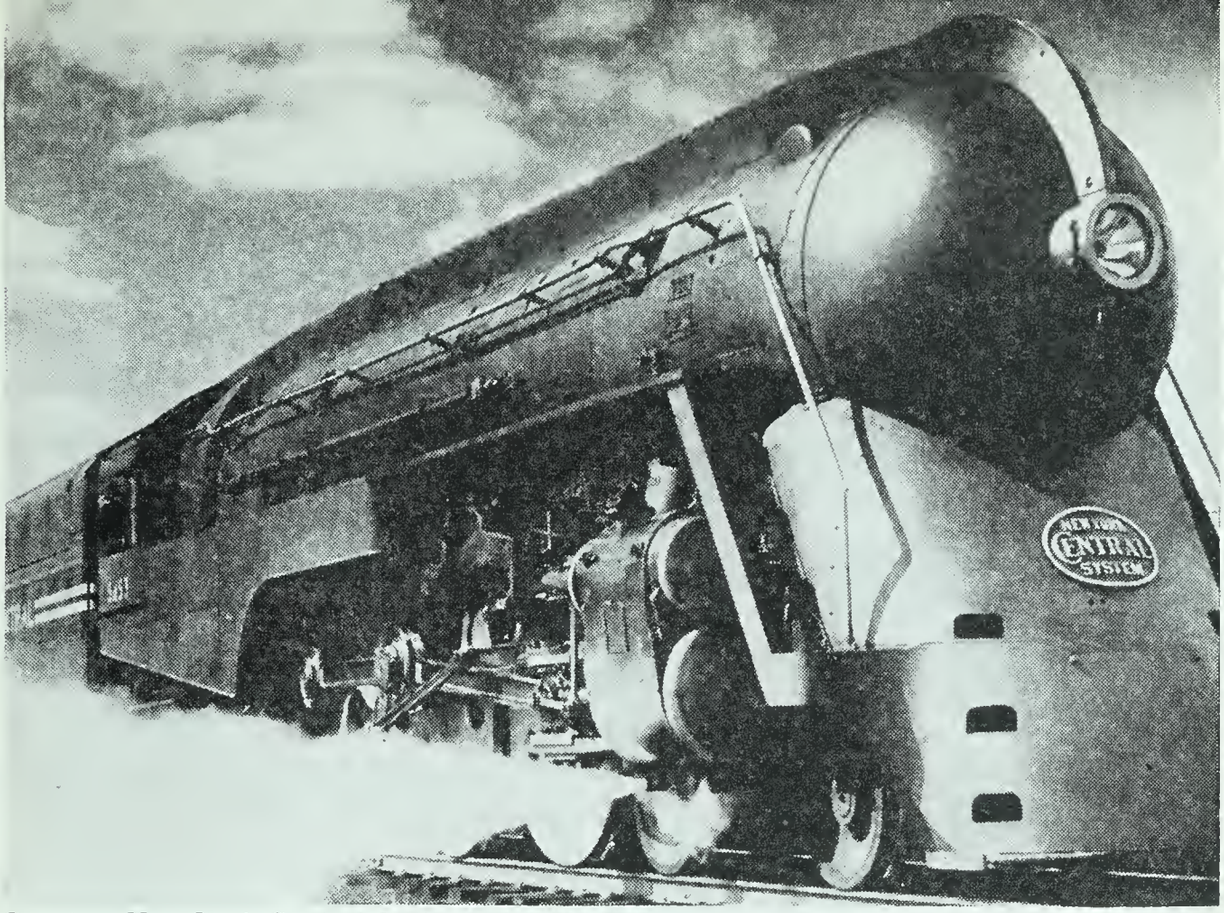
repeatedly from one end of the cylinder to the other. Because of this to-and-fro motion, this type of engine is called a *reciprocating* engine.

Since steam engines are usually designed to drive wheels, reciprocating motion must be changed into rotary motion. This change is effected by attaching the piston rod to a wheel at a point a short distance from the axle upon which the wheel rotates. Such an attachment is called an *eccentric.* Another eccentric mounted on the same axle does just the opposite—it converts rotary motion into the reciprocating motion which moves the slide valve backward and forward. The movement of the slide valve is timed to give proper direction to the flow of "live" and exhaust steam as previously described.

Obviously, there are moments while the slide valve is shifting its position and the piston is at either end of the cylinder, when little or no force is being exerted upon the piston. These are known as "dead points." Under a heavy load the engine would slow down or stop because of these dead points. To overcome this difficulty, a heavy flywheel is also mounted on the axle. Because of its weight, it has a strong tendency to keep moving when once set in motion. By exerting this force of inertia through the eccentric to the piston rod, the kinetic energy of the flywheel carries the piston rod past the dead points and produces a steadier motion in the machine.

The exhaust steam leaves the cylinder of the simple engine at greater than atmospheric pressure. This means that it can still exert some expansive force. For this reason, compound engines, in which the exhaust steam from one cylinder is led into a larger cylinder for further expansion, are built. Double, triple, and even quadruple expansion engines are built. Locomotives usually have compound engines.

In spite of all attempts to eliminate waste, even the most efficient engines turn a comparatively small part of the heat energy of the fuel into power. With coal as the fuel, ordinary steam engines



Courtesy New York Central System

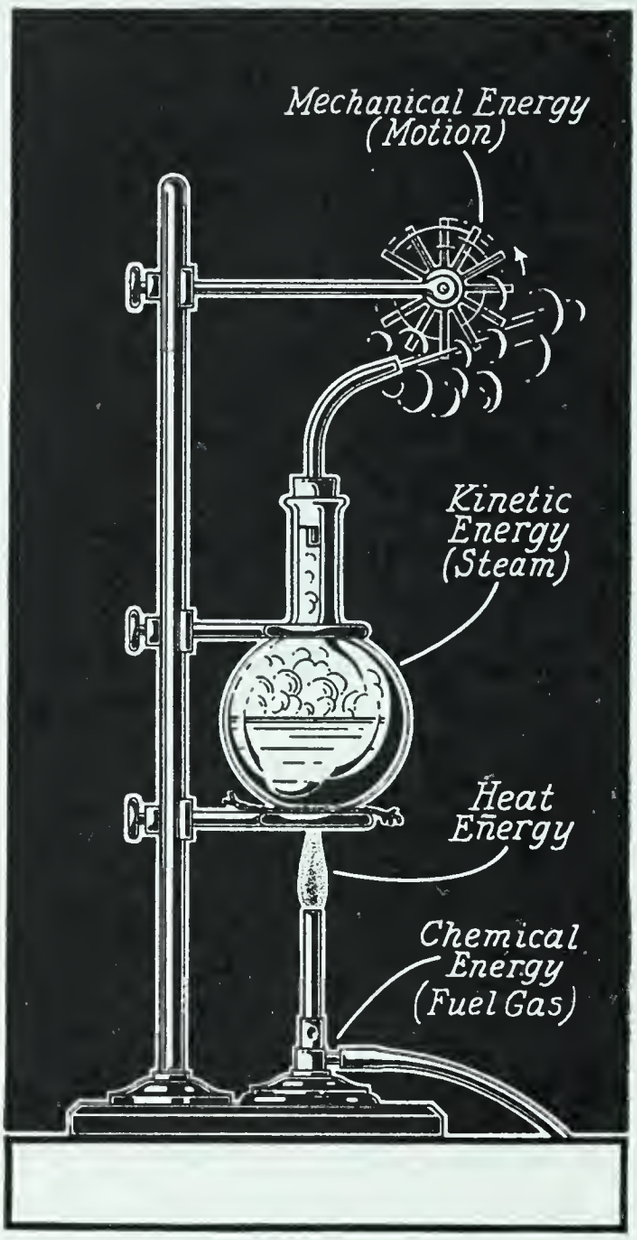
Streamlined steam power! Passenger-train locomotives have been the first to be streamlined not only to make more speed but to add "glamour" to their appearance.

waste about 89 per cent of the heat from the fuel, and even the most efficient ones waste more than 75 per cent of the energy supplied them. With oil as the fuel, the steam engine may do better and waste only 60 per cent of the energy supply.

The steam turbine overcame a serious defect of the steam engine. In the steam engine, the piston and its connections repeatedly slow down, stop, and start again in the opposite direction. This tends to make high speed difficult, to cause vibration, and to decrease efficiency. Watt recognized this and, like many others before him, was impressed by the idea of the Greek, Hero, who, 130 years before Christ, had made a copper ball revolve by its reaction to steam spouting from radial arms attached to the sides of the ball. Sir Isaac Newton (1642-1727), an English philosopher and mathematician, formally stated the idea behind Hero's engine when, in his third law of motion, he said, "To every action there is an equal and opposite reaction."

Many attempted to build a rotary steam engine which would eliminate the to-and-fro motion of the piston. They were handicapped because mechanics of the eighteenth century lacked precision tools with which to build machines exactly as specified in drawings.

Another development in turbine construction was accomplished



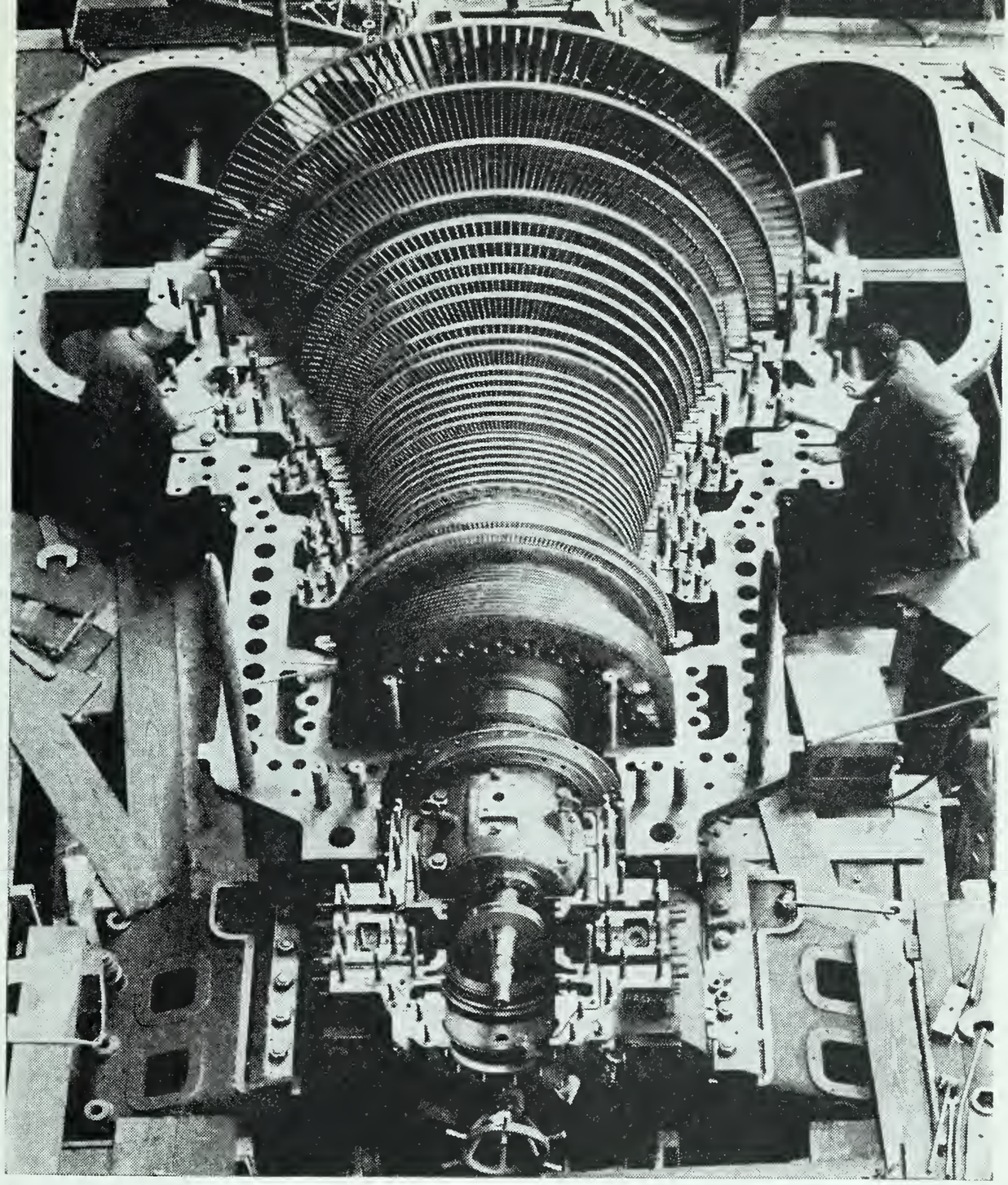
The diagram above illustrates the principle of the impulse turbine.

by Charles Parsons, an English engineer, who successfully applied the reaction principle of Hero. In 1884, he patented the first multistaged turbine. It was called a multistaged turbine because it consisted not of one wheel, but of a long rotor with many sets of rotating blades separated by other sets of stationary blades which gave direction to the steam as it forced its way through the encased rotor. The steam thus passed through many stages of alternately moving and stationary blades and, before finally escaping, set the rotor of Parson's turbine spinning at a rate of 18,000 revolutions per minute.

In 1889, Gustaf de Laval, a Swedish engineer, in attempting to provide better motive power for cream separators, perfected a turbine capable of turning with the remarkable speed of 30,000 revolutions per minute. De Laval's turbine was an impulse turbine; that is, blades of a wheel were given impulses by steam blown against them. The underlying principle of this engine was quite different from the original idea of Hero.

In the modern Curtis turbine, the impulse and reaction principles have been combined. The steam is first directed against curved blades much the same as in De Laval's turbine. Then it passes through stages of movable and fixed blades as in Parson's turbine. The diameter of both the casing and the rotor is made increasingly larger toward the outlet end to encourage the expansion of the steam. Such turbines are used today to drive electric generators and ocean liners. Turbine units which develop 100,000 horsepower or more are not unusual.

Both the reciprocating engine and turbine have advantages

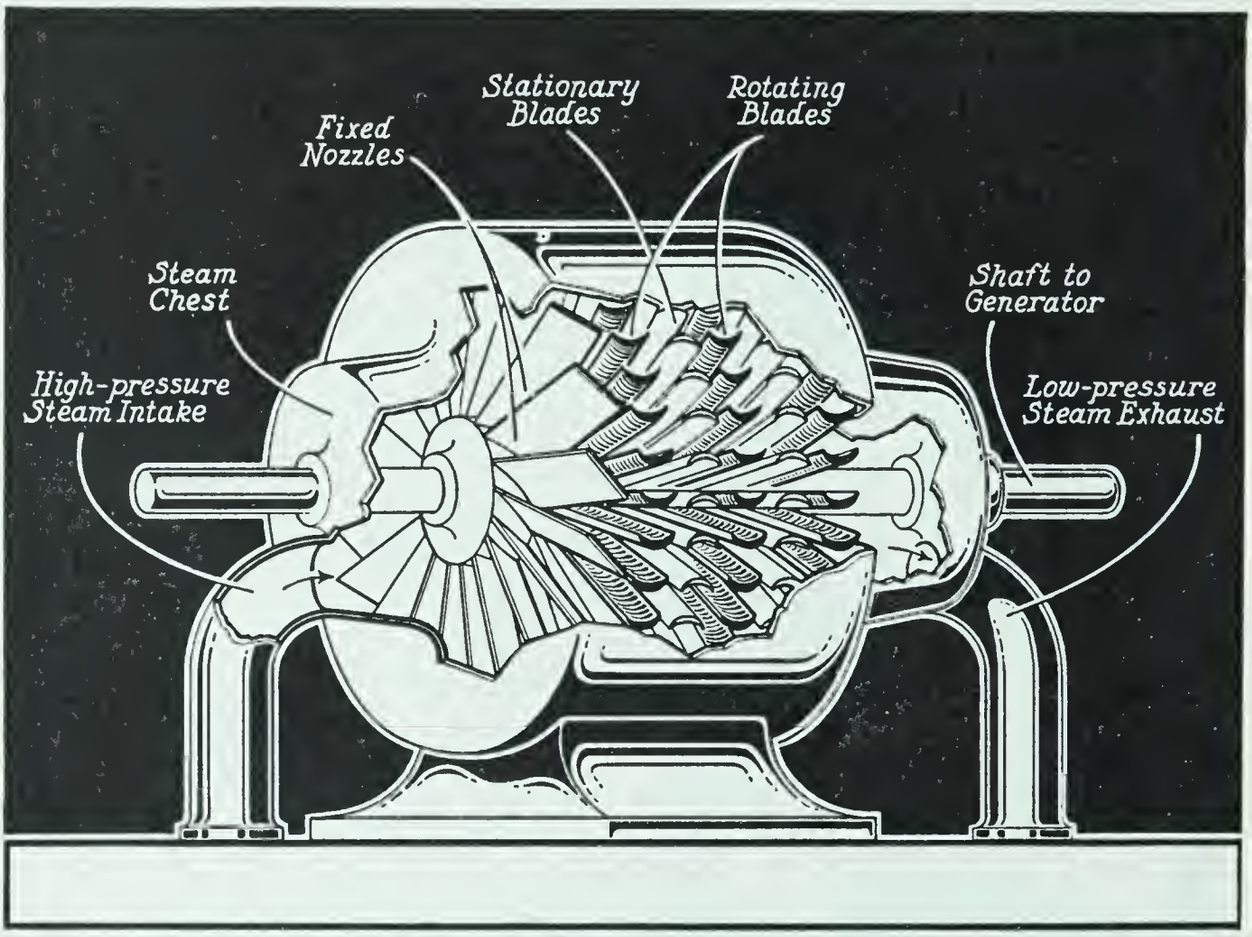


Courtesy Westinghouse

This cylinder base with the rotor in place is for a 60,000-kilowatt, 1,800-revolutions-per-minute turbine. Note the size of the workmen compared with the huge rotor.

which make it unlikely that either will be entirely displaced by the other. The turbine is more suitable for large units where very great speed is desirable. Since it can convert a little more than 30 per cent of the fuel's heat into power, it is more efficient than the reciprocating engine. The reciprocating steam engine, on the other hand, is more rugged and is very suitable for driving small mechanisms, especially where low or only fairly high speed is desired. Today we see it used on such machines as steam shovels, hoists, and cranes as well as on locomotives.

In 1680, Christian Huygens, a Dutch physicist, suggested that the explosive force of gunpowder could be put to work in an



The modern turbine involves both the impulse and the reaction principles.

engine. Subsequently, many attempts were made to develop an engine that would harness the force exerted by gases expanding after rapid burning. In 1876, N. A. Otto, a German, built a four-stroke internal combustion engine, the type of engine used in the present-day automobile and airplane. It is a more efficient engine than the reciprocating steam engine or steam turbine but uses a more expensive fuel.

The four strokes of the common gas engine are (1) the intake; (2) the compression; (3) the power; (4) the exhaust. These strokes follow one another in this order in each cylinder of the gas engine. To start the engine, the crankshaft is rotated with the aid of a crank or self-starter. As the piston of a cylinder is thus pulled down, a partial vacuum is formed above the piston, and the explosive mixture of gasoline vapor and air rushes into the cylinder through the open intake valve. This completes the intake stroke.

As the crankshaft continues to turn, the piston moves upward and compresses the explosive mixture in a small space above the piston. The gases cannot escape because both valves are closed during this second stroke. When the piston is at the top of its stroke, the ignition system produces an electric discharge at the

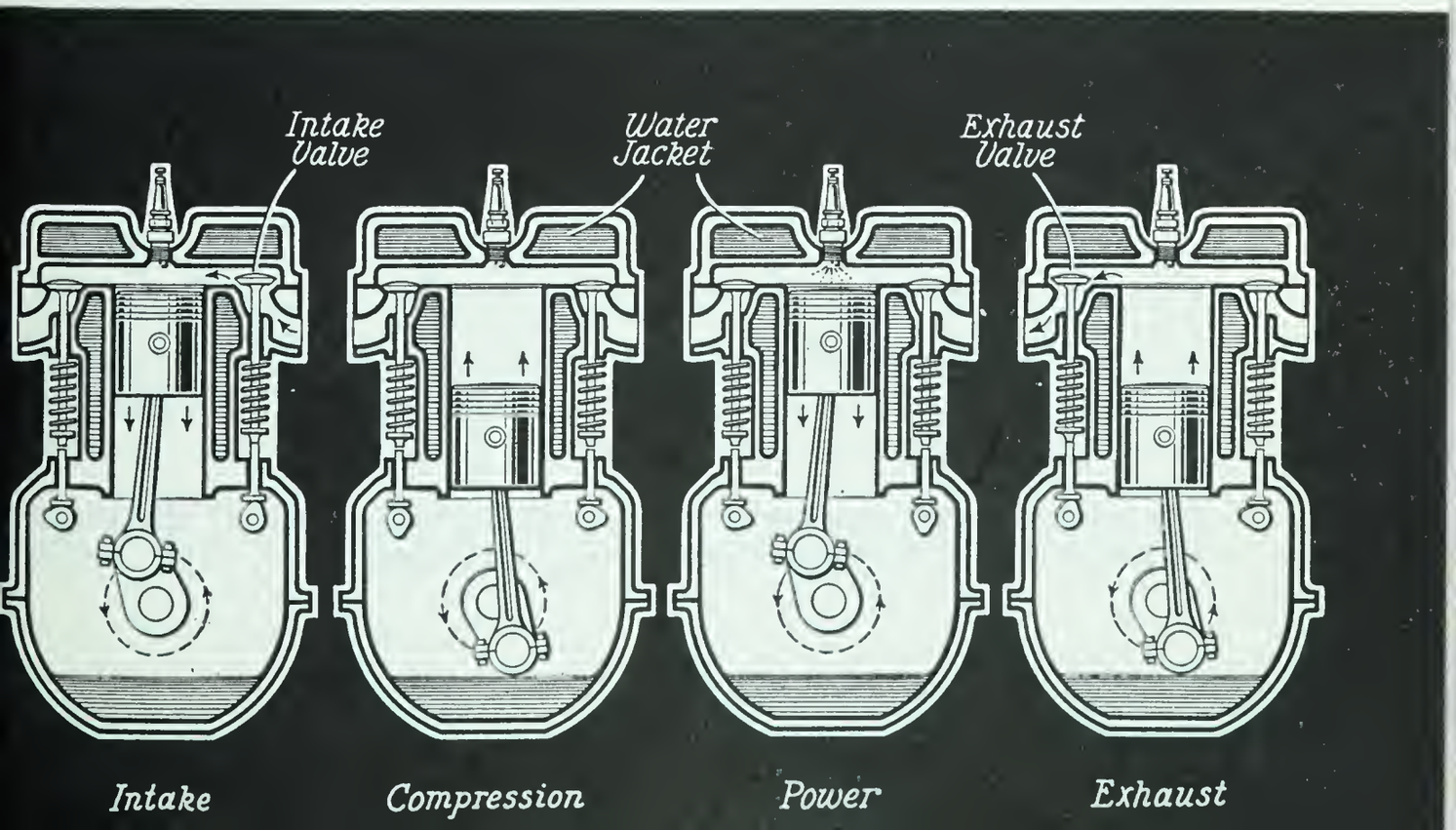
spark plug and the explosion follows. Oxygen in the mixture supports the combustion of the fuel gas which is raised to its kindling temperature by the electric spark. The piston is driven downward by the rapid expansion of the hot gases (chiefly water vapor and carbon dioxide) produced by the explosion. This "working stroke" is the only one of the four which delivers power. Hence, there is only one power stroke from each cylinder for each two revolutions of the crankshaft.

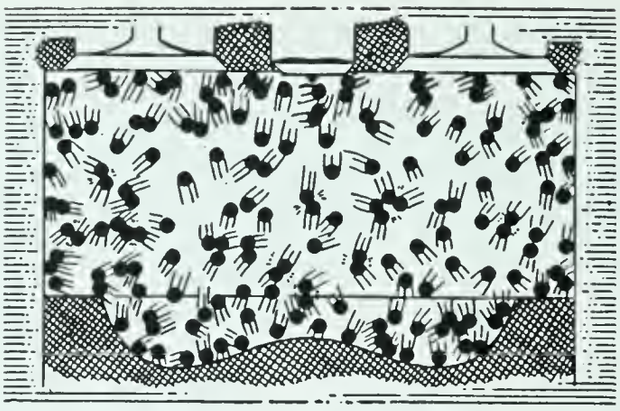
Inertia given the flywheel during the power stroke keeps the piston moving during the other strokes. During the fourth stroke, the piston moves up again and frees the cylinder of the gases formed during the combustion by expelling them through the exhaust valve, which is open in this stroke. The same sequence of strokes is repeated in each cylinder.

To get smoother performance, engines of more than one cylinder are built. They are timed so that the power strokes of the several cylinders follow regularly after one another. How much power the engine develops depends on three factors: (1) the capacity of the cylinders; (2) the degree of compression in each previous to the explosion; (3) the number of cylinders. Compared with an engine of fewer cylinders, a six-cylinder engine has a more even flow of power and can be run slowly with less danger of stalling; however, it is not necessarily the more powerful engine.

In 1892, Rudolph Diesel, a German inventor, patented another type of internal-combustion engine. Gasoline and Diesel engines

This drawing shows the positions of valves and piston during each of the four strokes in the common gas engine.



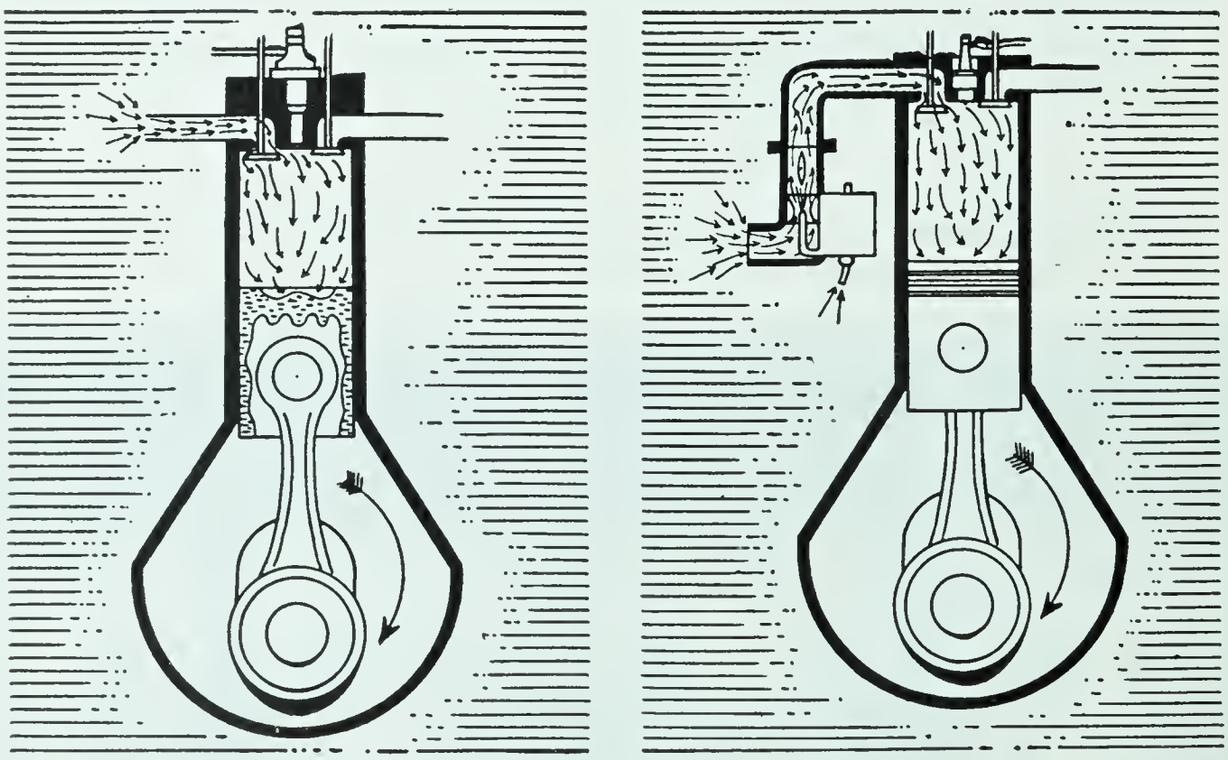


Courtesy General Motors Corporation

Above is shown the molecular action taking place during the power stroke in an engine cylinder.

look very much alike, because they both have cylinders, pistons, and crankshafts; and they are in most respects identical. However, there are fundamental differences—in the kind of fuel used, in the way in which the fuel is supplied to the cylinders and ignited, and in the degree of compression developed in the cylinders.

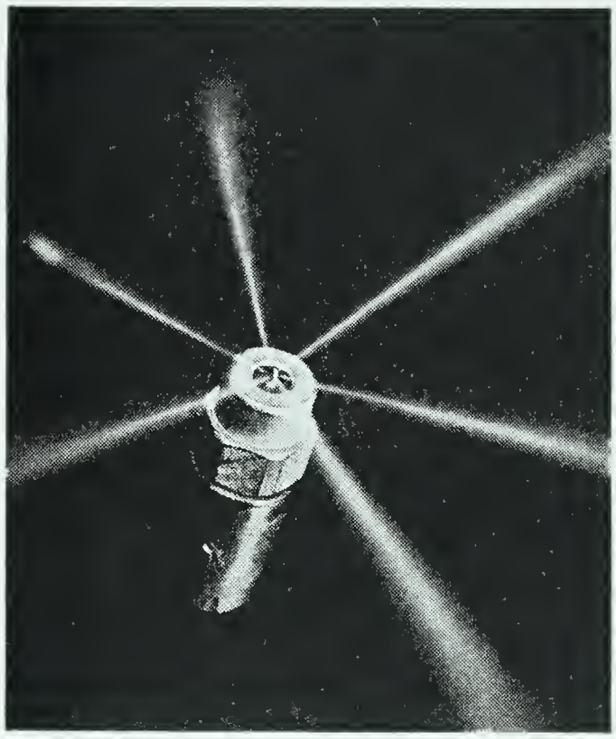
In the Diesel engine the air and fuel are mixed within the cylinders—not outside them as in the gasoline engine. The air is compressed by the piston; then fuel is injected into the cylinder at the end of the compression stroke. Therefore, an injector system takes the place of the carburetor of the gasoline engines. Since much higher compression is used than in gasoline engines, the temperature of the air rises higher in the Diesel engine during the compressing; a temperature as high as that of red-hot iron is reached. This superheated air automatically ignites the injected



Courtesy General Motors Corporation

The diagrams show the comparison of intake stroke action in the Diesel engine (left) and in ordinary gasoline engines (right).

fuel and thus eliminates any need for spark plugs, distributor, and condenser, which form the ignition system of the gasoline engine. If such high compression were attempted in gasoline engines, the high temperature would ignite the gasoline-air mixture before the compression stroke was completed. The engine would "knock" violently and might even start running backwards.



Courtesy General Motors Corporation

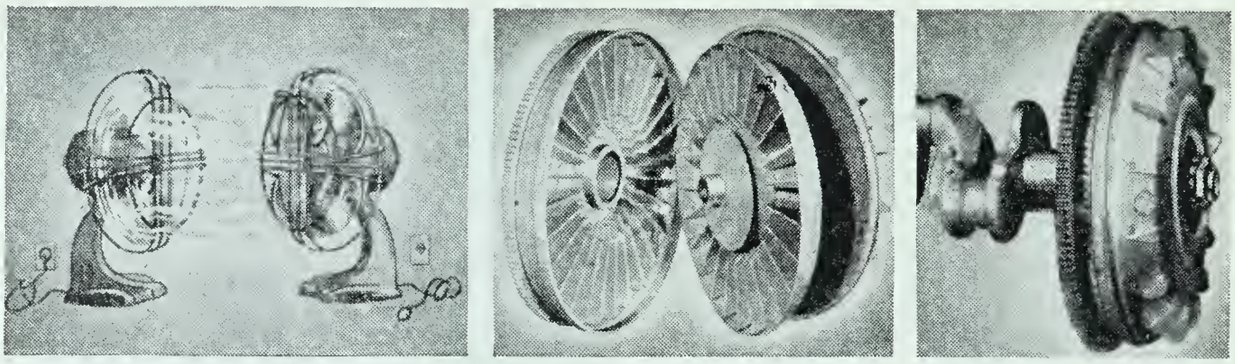
Above is shown the oil injector of a Diesel engine.

Diesel engines use oil as fuel. Since the kind of oil used is much cheaper than gasoline, the cost of operation is lower. Another reason why they are more economical to operate than gasoline engines is that in internal combustion engines, more efficient use of the fuel always results from higher compression. In recent years greater application of this principle in automobile engines has meant greater power, faster "getaway," higher speeds, and more miles per gallon of gasoline. However, the highest degree of compression possible in gasoline engines is much lower than that employed in Diesels.

The use of Diesel engines is rapidly increasing. The size of early ones limited their use to ships, tractors, and the like where a large power plant is not a great disadvantage. Today they are built in sizes as small as a large automobile gasoline engine; they are being used in increasing numbers as motive power for trucks, busses, turbines, submarines, and locomotives.

• THE AUTOMOBILE—GREATEST DEVELOPER OF POWER

About three-quarters of all power developed in the United States is generated in gasoline engines, and most of these are used to drive automobiles. This gives you an idea of the dependence of modern civilization upon transportation. You can see the rate at which changes are taking place in present-day society when you realize that there was not an automobile made in America



Courtesy Chrysler Corporation

How do the two electric fans illustrate the principle of transmitting power by fluid action? In the fluid transmission for automobiles, there is no mechanical connection between the driver and the runner; all energy is relayed by oil thrown by one against the other. Study the two photos of this type of clutch.

until after 1890; in fact, only a few crude ones had appeared by that time in Europe.

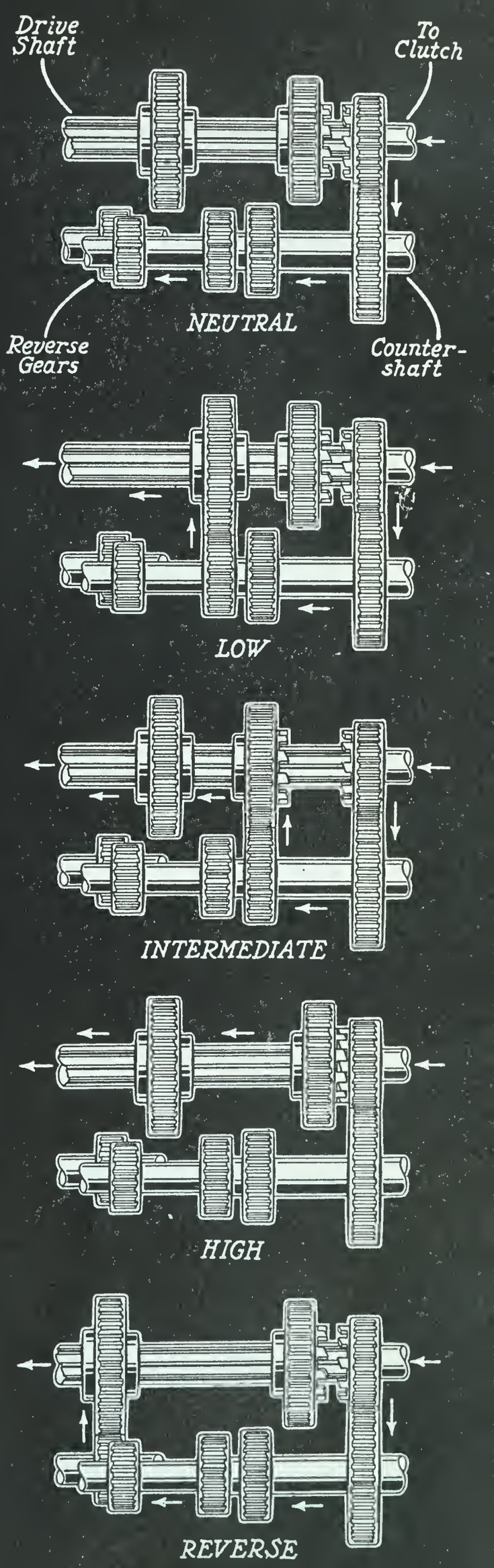
The modern automobile is an extremely complex mechanism. It is a fine example of man's ability to design many parts and to organize them into a unit for the accomplishment of a single purpose. In addition to the engine, the automobile has a system for transmitting the power to the wheels; an electrical system; a fuel system; a cooling system; a system of brakes; a chassis; and a body.

Unlike the locomotive, the automobile does not always have its power plant connected to the wheels. Since the gas engine supplies power periodically, it must be started under no load and allowed to build up inertia in the heavy flywheel before it is burdened with the task of setting the automobile in motion. Man has adjusted to the necessity of being able to connect or disconnect the power and load at will by inventing various types of *clutches.* These consist of one part attached to the crankshaft near the flywheel and another part attached to the transmission shaft, which relays the power to the wheels. The operator, with a clutch pedal or other more automatic device, joins these two parts when he wants to start the automobile and disengages them before bringing it to a complete stop with the brakes.

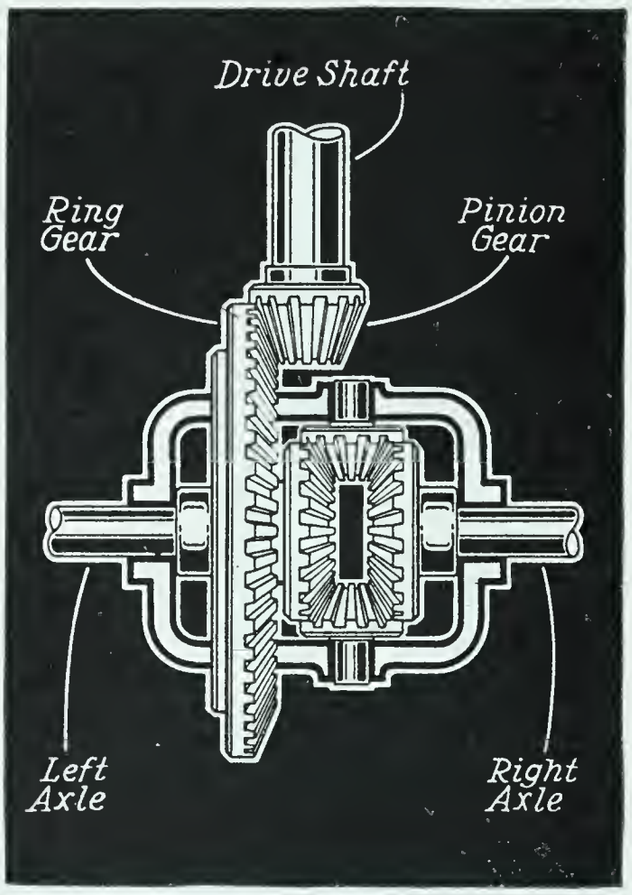
The mechanism of the automobile must be flexible enough to operate well under conditions that change rapidly. It must first perform the difficult task of starting and a moment later run efficiently at higher speeds on a level road. No matter what the velocity of the automobile, the engine itself always revolves at high speed, because it is not efficient at lower speeds. This raises

the problem of how it is possible to have a rapidly revolving engine drive an automobile at a rate of five miles per hour at one instant and fifty miles per hour a few minutes later. By controlling the gasoline supply with the throttle or accelerator, the high speed of the engine can be varied within rather wide limits, but a transmission system must be provided for the times when the car is starting or is greatly slowed down by the strain of climbing steep grades. Most modern automobiles have three speeds forward and one speed in reverse.

Three shafts which can be connected in several different ways by moving the gearshift lever make these various speeds possible. On some automobiles the shifting is automatic. Two of the shafts are in direct line with each other, and the third runs parallel to them. One of the shafts receives the power from the engine through the clutch as previously noted. During one of the speeds, known as third or high speed, this shaft is directly connected to the main drive shaft which is in direct line with it. At other times when the car is in motion,



Trace the flow of power through the automobile transmission, and explain how gears enable one to choose between power and speed.



The differential transmits power to the rear wheels without making it necessary for both of them to revolve at the same speed all the time.

these shafts are not directly connected, but the power is transmitted from the one to the other through the third parallel shaft. The shaft connections are made by means of gears which can be meshed or unmeshed by moving the gearshift lever. While the gears are being shifted, the operator disengages the engine and transmission system by means of the clutch. In the neutral position, there is no connection between the two shafts in direct line. This is the position used when the engine is running but supplying no power to the wheels.

Gear wheels in mesh can transmit power from one shaft to another in such a way as to turn the second shaft at a rate of speed different from the first. This is possible if the number of teeth on the meshed gears is unequal. If a gear of ten teeth is meshed with one of twenty teeth to transmit power from one shaft to another, the second shaft makes only half as many revolutions per second as the first. However, the second shaft has nearly twice the power of the first to compensate for the decreased speed. What we gain in power, we sacrifice in speed, and vice versa. The first or low speed, the second or intermediate speed, and the third or high speed position of the gearshift enables one to choose between power and speed when each is needed.

By using three gears instead of two and meshing them as shown in the diagram, the drive shaft can be driven in the opposite direction to that of the crankshaft. Thus the direction in which the drive shaft turns can be reversed while the engine continues to turn in the same direction as before. The position of the gearshift lever which effects this combination of gears is called reverse.

With universal joints as connecting links, the drive shaft transmits power from the transmission to the differential. The differential, as you can see from the diagram, lies between the two parts of the divided rear axle. It is a clever device which permits

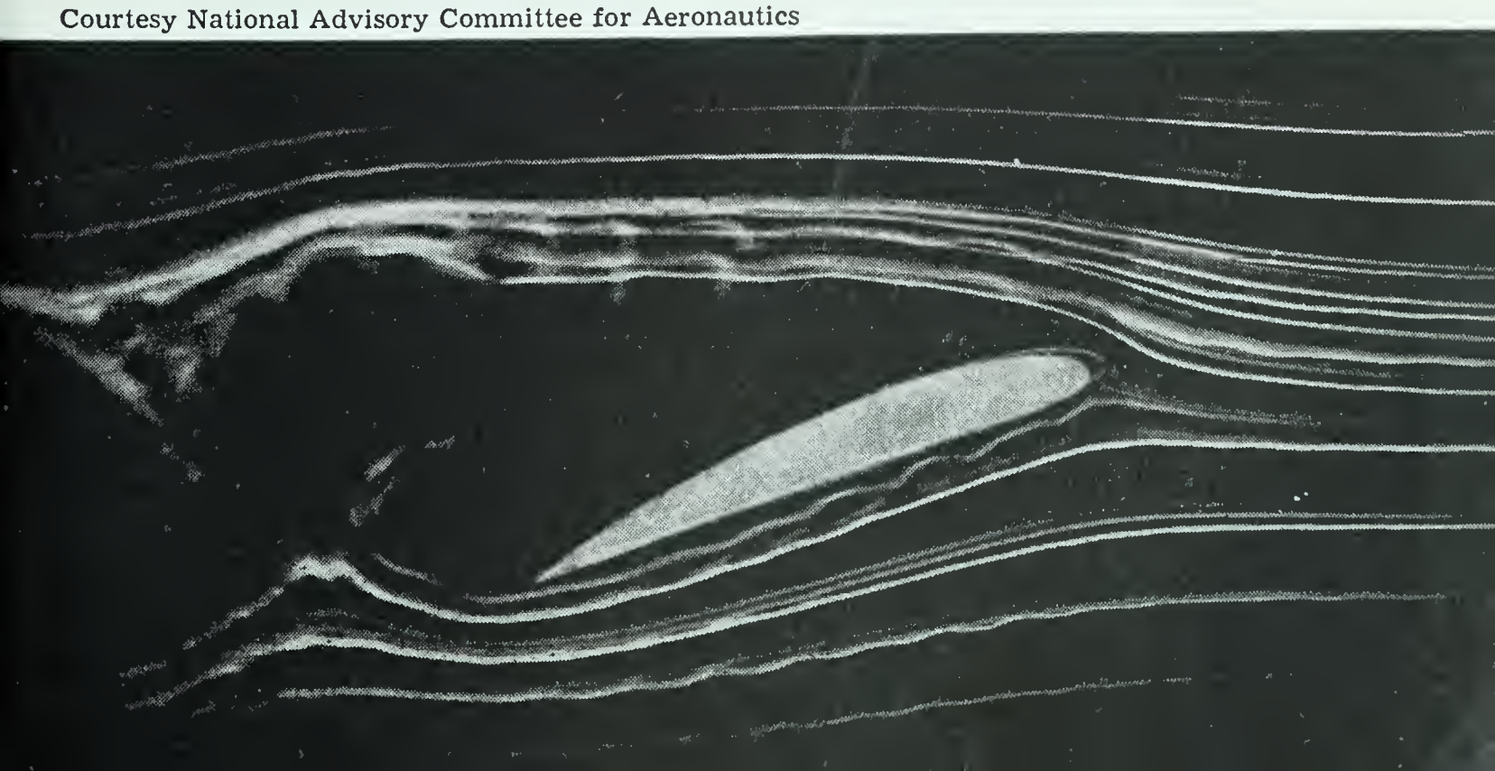
one rear wheel to travel faster than the other on curves. Since the differential allows one wheel to revolve while the other is stopped, it is obvious that nonskid chains must be used on both rear wheels to be effective on slippery roads.

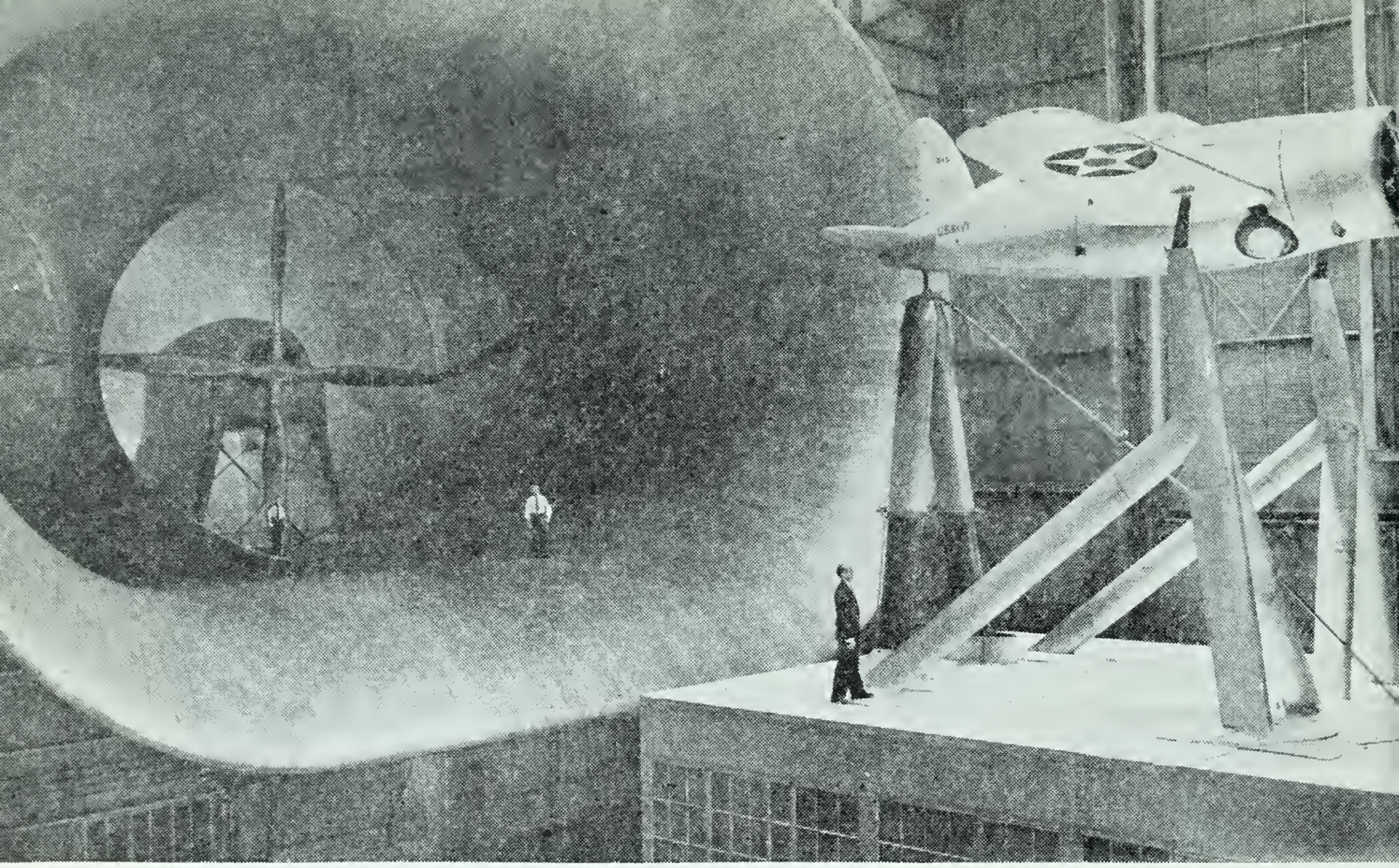
The function of the ignition system is to supply a spark in each cylinder every time a compression stroke is completed. To produce the spark at just the right moment in each cylinder requires a distributor and a timing device. Current is supplied by the battery, which is charged by a direct-current generator when the engine is running. A six-volt electrical system is usually used on passenger cars. Since higher voltages are required to produce the necessary sparks, the current passes through an induction coil which raises the voltage before the current goes to the spark plugs. A condenser is also inserted into the circuit to fatten the spark. The entire system must be accurately adjusted to produce the sparks when needed.

Brakes stop a moving vehicle by changing its energy of motion back into heat. Two types of brakes are used on automobiles: mechanical and hydraulic. In using mechanical brakes, the operator transmits force to the brakes through a system of levers; whereas, in the second type, an enclosed liquid transmits the force. This force causes the friction which slows down or stops the wheels by pressing the brake lining against either the outside or the inside of steel brake drums. Formerly, only the rear wheels of automobiles were equipped with brakes, but now they are found on all four

A four-stroke gas engine provides the motive power, but it is the action of the curved wings that causes the airplane to rise and stay aloft. This photograph of the flow of smoke streamers over a model of an airplane wing reveals the vacuum produced above the wing and the push of the air ("lift") against its lower surface.

Courtesy National Advisory Committee for Aeronautics





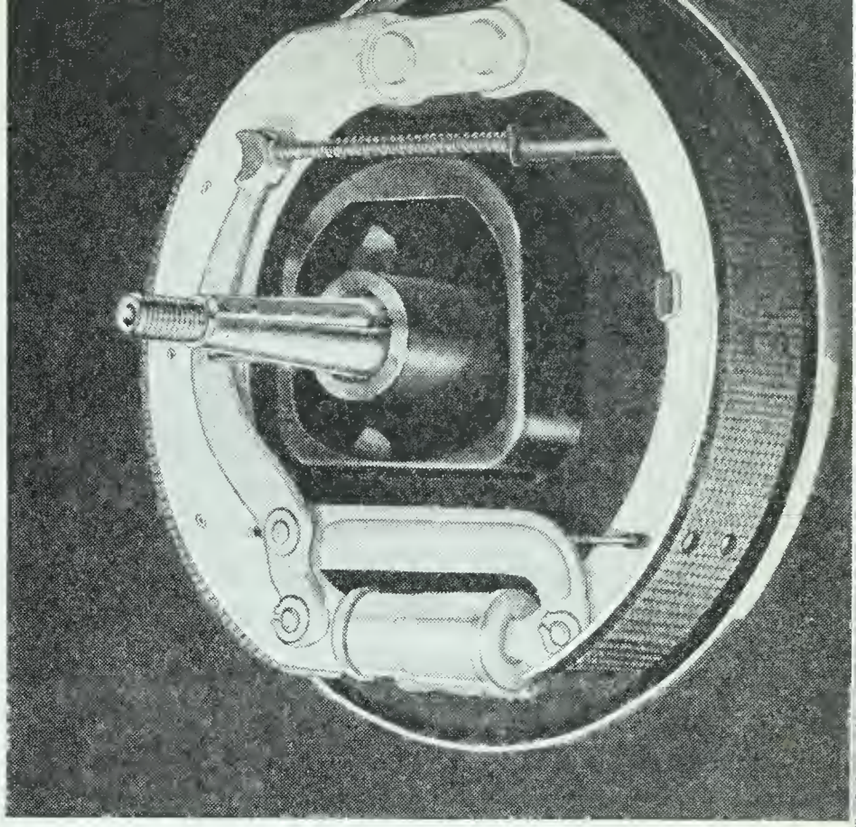
Courtesy National Advisory Committee for Aeronautics

This full-size airplane is mounted for a test in the largest wind tunnel in the world. The airplane is supported in the air blast on struts which transmit the forces to balances in the house below. Two 35½-foot propellers, operated by 4,000 horsepower electric motors, produce a wind of 118 miles an hour past the airplane.

wheels and are nearly 100 per cent of the hydraulic type. A mechanical emergency brake is also part of the equipment of every automobile.

• HIGHWAY AND TRAFFIC SAFETY

If the United States were struck by some epidemic which, during the course of one year, brought death to forty thousand persons and seriously crippled or endangered one million others, what would we do about it? Each year in this country, traffic deaths and injuries approach these staggering figures. Two-thirds of those killed in cities and one-third of those killed in rural districts by automobiles are pedestrians. The problem of improving such a threatening situation should be the concern of everyone. The person on the street, as well as the driver in the car, must cooperate. Safety campaigns in some states have shown that the number of accidents can be greatly reduced by precautionary measures. Revoking the license of the operator, for example, has proved far more effective in curbing reckless driving than making the driver pay a fine after an accident.



Courtesy Ford Motor Company

Power to stop is as important as power to start. By means of the hydraulic principle, gentle pressure on the pedal becomes a mighty grip at the brakes, assuring a quick, straight stop, as motion changes back into heat. A 100-horsepower automobile often has 500-horsepower brakes.

Some people expect brakes to do the impossible. The difficulty of stopping an automobile multiplies greatly as the car's speed increases. The kinetic energy of an accelerating automobile does not increase equally with its speed, but more nearly as the square of the speed. This means that doubling the velocity multiplies the kinetic energy—and hence the distance needed for stopping—by approximately four. If drivers fully realized this fact, there would be fewer accidents resulting from excessive speed. The operator should think of the car's speed in terms of the length of road necessary for stopping it—not merely as so many miles per hour. How many drivers know that, even under the best conditions, a stretch of road nearly equal in length to a football field is required for stopping a car traveling at a speed of seventy miles per hour?

STOPPING DISTANCES UNDER EXCELLENT CONDITIONS

(Using effective four-wheel brakes while motoring over a smooth, hard-surface, straight, level, dry highway.)

If you go this fost per hour	You will travel this distance per second	Danger ohead! Before your mind reacts to the situation, you will go this distance	You will go this much farther after brakes are applied before you stop	So you've gone this far after danger was seen before you stopped
20 miles	29 feet	22 feet	18 feet	40 feet
30 miles	44 feet	33 feet	40 feet	73 feet
40 miles	59 feet	44 feet	71 feet	115 feet
50 miles	74 feet	55 feet	111 feet	166 feet
60 miles	88 feet	66 feet	160 feet	226 feet
70 miles	103 feet	77 feet	218 feet	295 feet

(These distances are based upon a ¾-second interval elapsing between the time the eye or ear detects a danger and the time the brakes are applied. The data are based on studies by the Registry of Motor Vehicles, Rhode Island.)

Sometime, pace off a few of these distances. You will have a new appreciation of the dangers you face while traveling at high speed. Always have clearly in sight open road on which you can stop your automobile in an emergency. As we have already pointed out, the distance needed becomes greater at a surprising rate as the speed increases. Following too closely behind another car is a very common mistake that often results in collisions. Remember that the car will travel a considerable distance before you can even apply the brakes in an emergency, in addition to the distance required for stopping after the brakes have been applied.

Ranking close to excessive speed as a cause of death on the highway is improper passing of other cars. Many lives would be saved annually if motorists would resolve never to try to pass a car they are following near or at the top of a hill. Even though a slow truck is ahead, it is foolhardy to dart out blindly from behind it. You may become trapped between it and an onrushing car previously hidden by the top of the hill. Use caution in passing a car going in the same direction even on a level road. Before

A grim reminder of the perils of speed is this wrecked car, smashed up beside a sign warning against fast driving. Remember that signs like this are meant to protect YOU!

Courtesy Travelers Insurance Company



trying to pass, drop back to allow space for accelerating to a greater speed than that of the car ahead. Then, if the road is clear, give warning with the horn and accelerate again, pulling to the left for passing. Be careful not to "cut in" too soon on the car just passed. This method of passing gives the least possible exposure to danger.

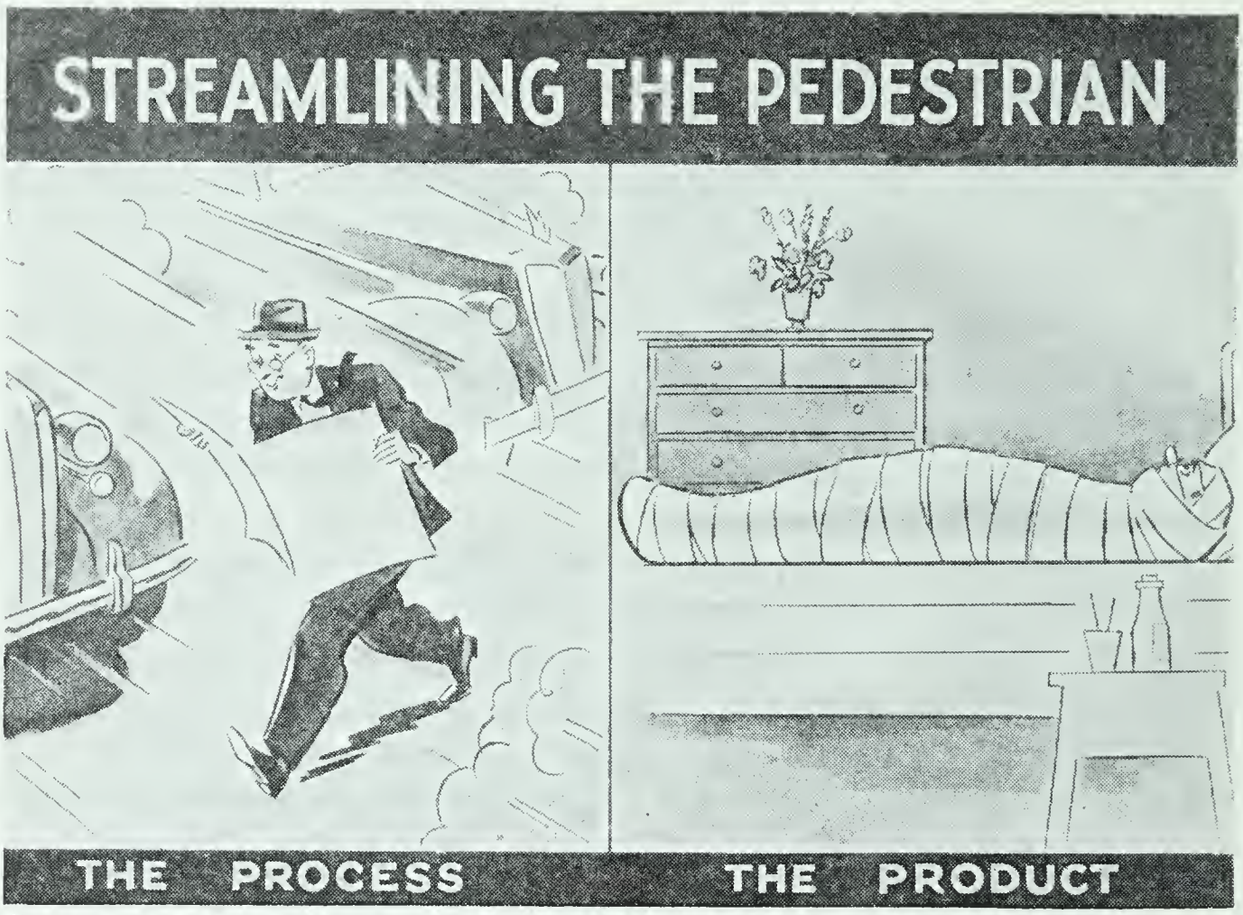
Another place where passing is dangerous is on curves, as the road ahead cannot be seen. High speed is also extremely dangerous; slow down before turns are reached, since the car is likely to skid if the brakes are applied on a curve. About 10 per cent of all highway deaths happen at curves.

Greater care at intersections and strict observance of traffic signs and signals would contribute greatly to safer motoring. It is unwise to proceed at dangerous spots before knowing what the other motorist is going to do. Motorists should make known their intentions by proper hand signals before they change the direction or motion of their car. Unfortunately, there is no standardized system of signaling throughout the country. Proper consideration and courtesy should be extended to pedestrians, as well as to other motorists.

Another duty of every car owner is to keep his automobile in good condition. A car with defective brakes, improperly adjusted headlights, defective steering apparatus, or worn-out tires is a menace on the highway, no matter how expert the driver may be. Where states have required periodic inspection of all automobiles, a large percentage of them have been found to be defective in one way or another. If you own a car, help save lives by having it inspected regularly by a good mechanic, even if your state does not require it by law.

Most pedestrian deaths occur at and between the intersections of city streets, or on open stretches of country roads. Among the most common errors committed by pedestrians in the city are (1) stepping from the curb without first seeing that it is safe to do so; (2) crossing streets between, rather than at, intersections; (3) disregarding traffic signals; (4) darting out into the street from behind an obstruction, such as a parked car. Each of these errors suggests its own remedy.

About one of every thirteen persons killed by automobiles meets death while walking on country roads. Reckless speed of automobiles is a big factor over which the pedestrian has no control. There are, however, two things you can do to protect yourself when walking along highways: (1) Always walk on the left side of

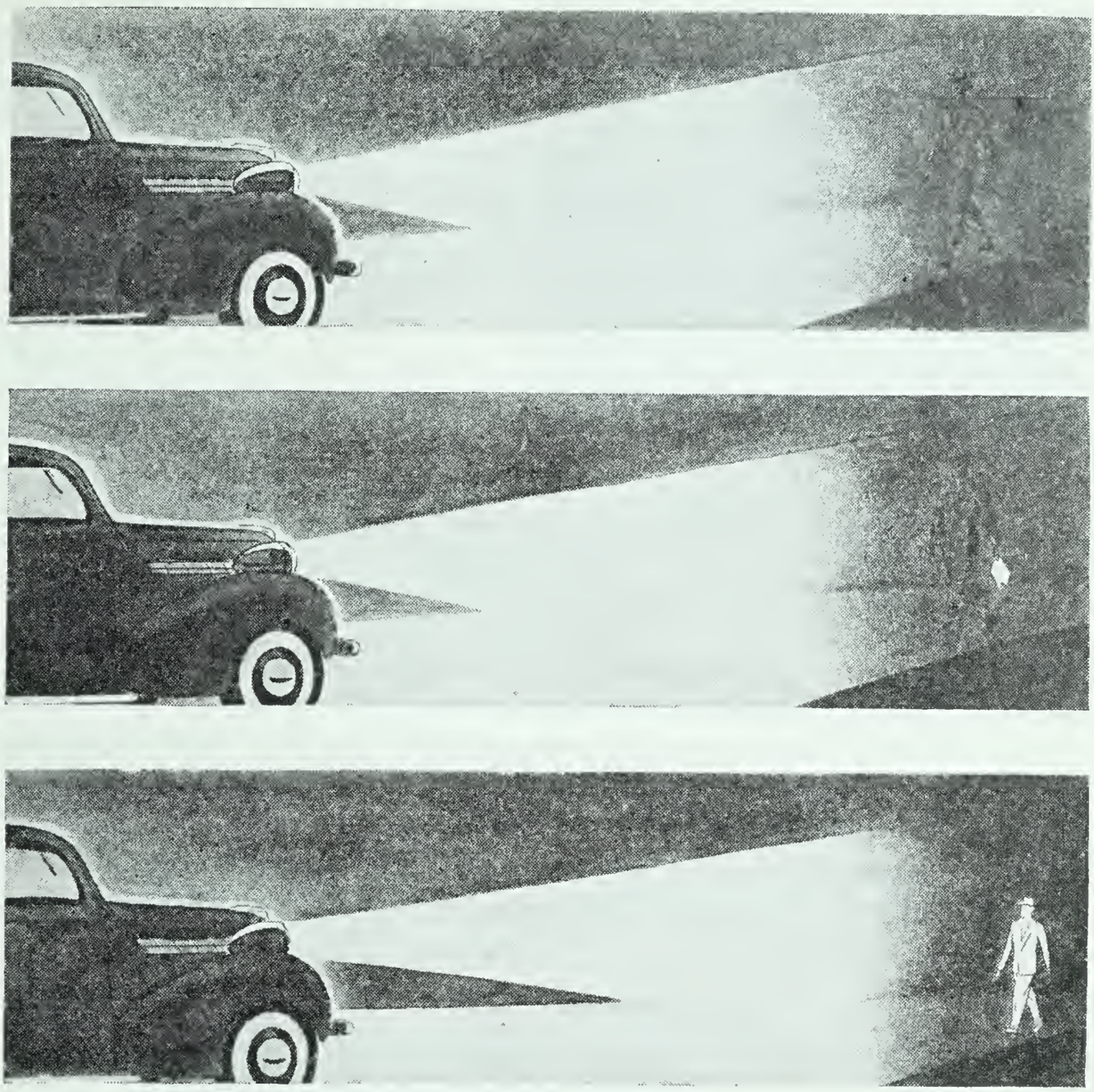


Courtesy Travelers Insurance Company

the road so that you can see approaching traffic; (2) when walking after dark, help the motorist to see you by carrying a light or some good reflector of light, such as a piece of bright metal. We see things only when light from them reaches our eyes. It is almost impossible at night for a driver to see a pedestrian who wears dark clothing and fails to use some special device for making his presence known.

Few accidents are caused on the highways by those who extend to others the courteous treatment that everyone likes to receive. Good manners always reveal respect for the rights of others, but on the highway they do more—they help to prevent injury and death. There is satisfaction in displaying good sportsmanship when motoring, because pedestrians and motorists are unusually appreciative of generous acts. No doubt you can recall the deep sense of gratitude you have felt as some motorist waited and signaled you to continue when the changing of a traffic signal would otherwise have left you stranded in the middle of an intersection. On the other hand, there have no doubt been times when you have thought that the honking of a horn was a hostile act.

Although we can ordinarily refuse to associate with the person whose bad habits make him repulsive, unfortunately there is no



Courtesy Travelers Insurance Company

The driver won't hit what he can see. Carrying a small light or wearing light clothing makes it easy for the driver.

easy way to avoid being exposed to his selfishness on the road. But we should remember that each of us has some bad habits that we do not know about because habits work automatically. For this reason, occasionally consider your actions on the highway and check them for soundness and good sportmanship.

Exercises for Problem Study and Review

1. How do we account for the fact that winds and running water possess power? What is the source of the energy they possess? Explain.
2. What determines whether a Pelton wheel or a turbine is used to harness the energy of water?

3. What is the importance of these sources of power today?
4. How is power obtained from steam today?
5. Why are steam and mercury boiler combinations frequently used instead of steam boilers only? Compound steam engines instead of simple steam engines?
6. How is steam power applied today?
7. Explain the impulse and reaction principles underlying the action of the modern turbine.
8. Give several examples of inertia and of Newton's law of "action and reaction."
9. Why is neither the reciprocating engine nor the turbine likely to be entirely displaced by the other?
10. How does the gasoline engine develop power?
11. In tabular or chart form, compare the Diesel engine and the gasoline engine in as many ways as you can.
12. Outline the purpose and action of each of the systems found on the automobile.
13. Trace the flow of power in an automobile from the motor to the rear wheels.
14. The speed of a moving automobile is tripled. What happens to (1) its kinetic energy? (2) The tendency to overturn at curves? (3) The distance needed for stopping?
15. What modern social problems have resulted from the increased development of power, particularly by the automobile engine?

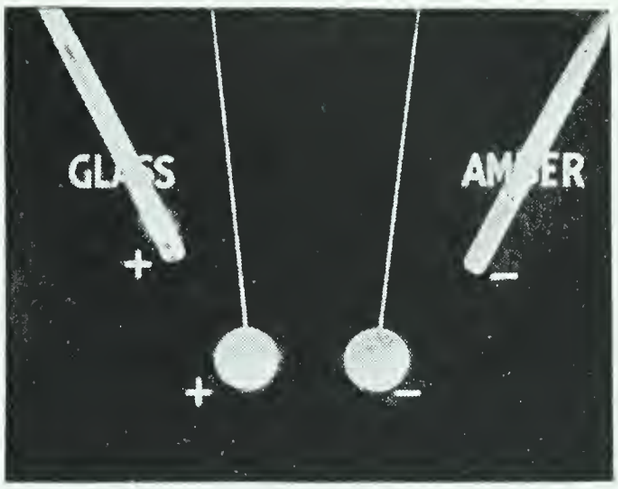
Problem 2: How does man generate electricity?

• ELECTRONS AT REST

The discharge of lightning and the crackling sound produced by stroking a cat's back in dry, cold weather are evidences of electrification. By shuffling the feet across a wool rug and touching a radiator, a light switch, or another person, we can see a spark and feel a shock. We say it is electricity. This kind of electricity is called *static electricity* because the charges are at rest. Static electricity is interesting, but its practical applications are rather few in number. Nevertheless, a review of man's knowledge about static electricity will help us to understand how man makes adjustments to another, more useful kind—namely, *current electricity*—so called because the charges are in motion.

Static electricity can be generated by friction. The story of

man's experiences in producing static electricity dates back to 600 B. C. At about that time, the Greek philosopher Thales discovered that a piece of amber, when rubbed briskly, attracts pieces of straw, chaff, and dried leaves. Since the experimental method of testing discoveries had not yet been devised, the ancients had many mystical explanations for this attraction by amber and nothing of scientific worth came from the discovery at that time. It was merely a curiosity.



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Like charges repel each other, and unlike charges attract each other.

About 2,200 years later, William Gilbert, physician to Queen Elizabeth of England, discovered that other materials, like sealing wax and glass, can be made to attract certain kinds of small objects when electrified in this way. Gilbert could not explain the effects of this force, but he named it "electricity," a word derived from the Greek word for amber. Since then, experimenters have designed and built many kinds of machines for generating frictional electricity.

There are two kinds of static charges. Anyone can experiment with static electricity by using very simple materials. To produce the charges, rub a hard glass rod with a piece of silk or rub a rod of bakelite, hard rubber, or sealing wax with wool or fur. Atmospheric conditions are a factor to be considered. Best results are obtained when the air is dry and cold, as on a crisp winter day; warm, moist air allows electricity to escape.

To study the nature of static charges, suspend by silk threads two small pith balls, or two ping-pong balls coated with tin foil or aluminum paint. Rub the balls with a charged glass rod, and notice how they stand apart, or repel each other. Notice that they are also repelled by the glass rod but are attracted by a charged rod of bakelite, hard rubber, or sealing wax.

From a great number of such experiments, scientists have drawn two important conclusions: (1) There are two kinds of electric charges—the kind produced on a hard glass rod by rubbing it with silk and the kind produced on a hard rubber rod by rubbing it with fur; (2) like charges repel each other, and unlike charges attract each other.

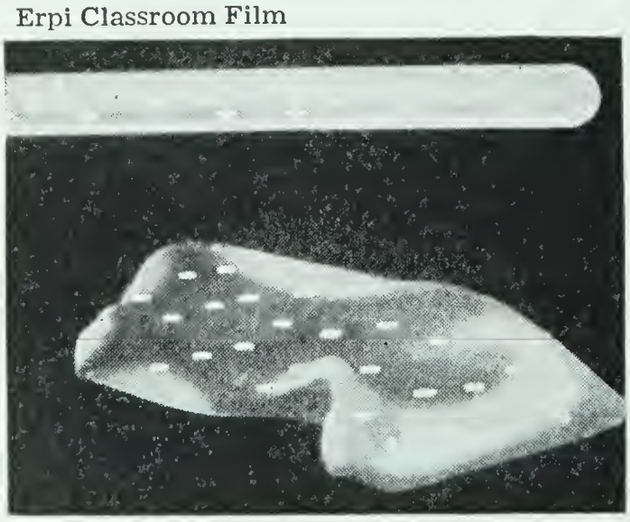
Static charges result from a loss or gain of electrons. We can account for the production of static charges and interpret the effects of static electricity by the hypothesis that *all matter is composed of positive and negative electricity in equal amounts.* In other words, we assume that electricity is everywhere in all things: glass, hard rubber, metals, water, paper, air, even our bodies. Positive electricity occurs in units called *protons,* while negative electricity occurs in units called *electrons.* Ordinarily, matter contains equal numbers of positive and negative units. Since one positive charge neutralizes one negative charge, neither kind of electricity reveals itself. If an object has an excess of either positive or negative electricity, it is said to be electrified, and it exerts an electric force. Ordinarily, only negative electricity (electrons) can be transferred. Thus a body has a negative charge when it has an excess of electrons; a positive charge results from a shortage of electrons.

When we stroke a hard rubber rod with fur, thus producing a negative charge on the rod, we really cause some electrons to transfer from the fur to the rod. Likewise, in charging a glass rod with positive electricity by rubbing with silk, we actually cause electrons to move from the glass to the silk. Thus, whenever we produce electrification by friction, two equal and opposite kinds result—one kind on the rubbing cloth and the opposite kind on the article rubbed.

The terms *positive* and *negative* are holdovers from a discarded theory of electricity suggested by Benjamin Franklin. He considered electricity to be a fluid which could be gained or lost by rubbing. Franklin suggested that the charge on a glass rod rubbed with silk was due to an excess of this fluid and that it be called positive, or plus, electrification. Likewise, he thought that the charge on a sealing-wax rod rubbed with flannel was due to a shortage of this fluid and called it negative, or minus, electrification.

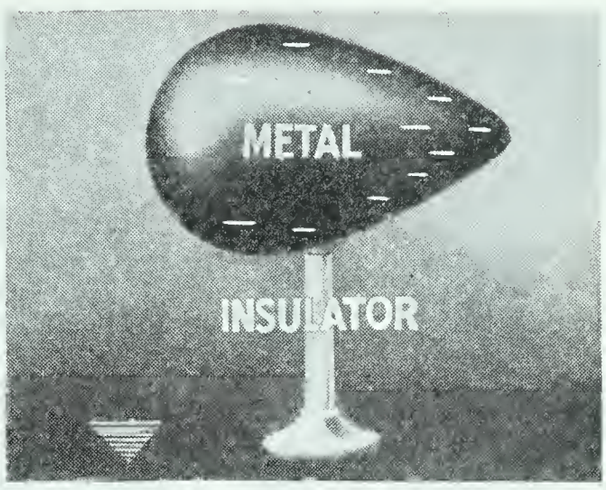
Whenever electrification is produced by friction, two equal and opposite kinds of charges result.

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Materials may be classed as conductors or insulators. Thus

far we have considered only the charging of materials like glass, sealing wax, and hard rubber. The reason is that charges on such materials remain localized. If we try to electrify a rod of copper or aluminum while holding it, we meet with failure because the charges can move and they escape through the human body as rapidly as produced. If a metal object is well insulated, however, it can be charged.



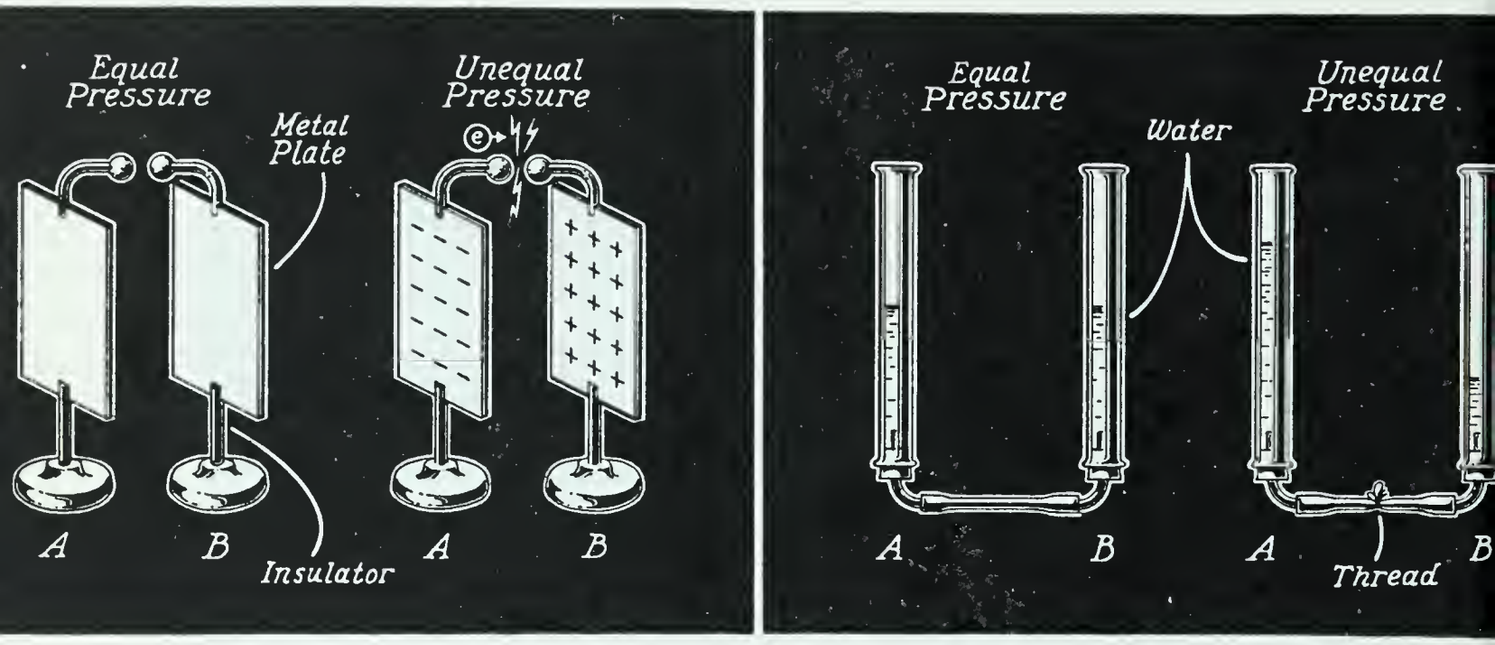
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A metal object, if well insulated, can be charged.

Metals are good conductors of electricity, while materials like rubber, porcelain, glass, sulfur, dry air, pure water, and paraffin are not. Materials that do not conduct electricity very well are called *insulators.* There are no perfect conductors and no perfect insulators; all conductors offer some resistance to the passage of electricity, and even the best insulators "break down" under very strong electric forces and become conductors. Ordinarily, metals are used to provide the pathways for the flow of electricity, while porcelain, glass, oil, silk, bakelite, paper, and rubber are used to prevent it from "jumping the track."

Safety requires proper adjustments to static electricity. In factories, the leather belts used on some machinery often build up heavy static charges which become hazardous, particularly where there is an inflammable gas or a combustible dust in the air, as might be the case in flour mills and sugar refineries. Sparks resulting from the discharge of such electricity have often caused disastrous explosions; consequently, special precautions are taken to prevent the accumulation of static electricity. There is also danger of fire and explosion caused by frictional electricity whenever fabrics are cleaned or floors are scrubbed with gasoline. In spite of widespread knowledge of this fact, each year many people unnecessarily suffer severe burns or die from this cause. The use of noninflammable cleaning fluids, such as carbon tetrachloride, would make such accidents impossible.

Gasoline trucks would become charged as they travel on the roads, due to the random motion of the gasoline within, if precautions were not taken. The charge tends to accumulate because the rubber tires insulate the truck from the earth. The accumu-



Electrical pressure or voltage can be compared to water pressure.

lation of a heavy charge might cause a spark to jump and set fire to the vapors when gasoline is being delivered. To prevent such an occurrence, the truck is "grounded" by a dangling chain which strikes the road as the truck moves along. This permits the charge to escape as rapidly as it is formed.

Electrical pressure results from differences in electrical condition. Let us consider two insulated metal plates, A and B, to each of which is attached a wire terminating in a knob. When both plates contain equal numbers of positive and negative units of electricity, they are neutral and no current flows when the knobs are touched together. If we charge plate A by giving it some extra electrons, the two plates will differ in electrical condition, or potential. When the knobs are caused to touch, plate A shares its charge with B; in other words, a flow of electrons, or current, results. Before the knobs were brought together, the air gap between served as an insulator and prevented the flow of current. If the potential difference between the two plates is made great enough, however, either by giving plate A some more electrons or by removing electrons from B, the electrical pressure that results will "break down" the insulator, and a spark will jump across the air gap. Both plates will then be neutral and the potential difference will be zero; likewise, the *electromotive force* (the force that motivates, or drives, electrons) will be zero.

Potential difference (P.D.) and electromotive force (E.M.F.) are ordinarily spoken of as voltage. It is easy to understand voltage by comparing it with water pressure. If we have two glass

tubes connected by a length of rubber tubing as shown in the drawing, water will flow between A and B only when there is a pressure difference between them. If the water level is higher in A than in B, water flows toward B; likewise, if the water level is higher in B than in A, water flows toward A. As soon as the water comes to the same level in both tubes, the flow stops. Now, if we tie a fine thread tightly around the rubber tubing, no water can flow even though water is taken from B and added to A. A *pressure difference* develops, but there is no *current* because of the thread. We can imagine, however, that enough water could be poured into A to cause a pressure difference great enough to break that thread. Then water would gush rapidly through the tubing toward B. This corresponds to the breakdown of the insulating air gap and the jumping of the spark between the two electrically charged plates when their potential difference becomes great.

• ELECTRONS IN MOTION

A continuous current of electricity results only when a potential difference is maintained. At present, static generators are impractical for the commercial production of current electricity because the current is small and intermittent, although of high voltage. A laboratory static machine demonstrates this fact. The machine must be operated for a while to build up a difference of potential; then there is a momentary spark, and we have to start all over again. If we could maintain a difference of potential, there would be an ever-present electromotive force, and the flow of electrons would be continuous. That is just what we need to run electric motors; to drive trains and ocean liners; to keep refrigerators cold; to make toasters hot; to light our homes; and to transmit speech and music across land and sea.

Our present electrical age has resulted from the discovery and development of two important methods of maintaining a potential difference: (1) by chemical action; (2) by mechanical generation. Most of our electricity comes from huge generators in central power stations, but there is such a demand for electricity from chemical action that millions of dry cells are manufactured each year. Storage batteries likewise produce electric currents by chemical action, but we shall learn about them later.

The first chemical cell for producing a continuous current was devised by Count Alessandro Volta, an Italian. His countryman, Luigi Galvani, discovered that a frog's leg, recently dissected from

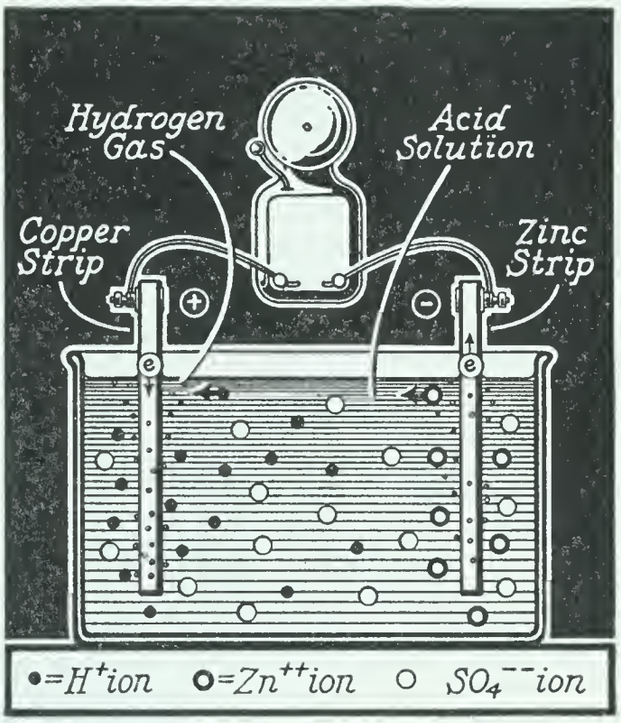
its body and suspended by a copper wire, will twitch as if alive when touched with an iron knife. He thought that electricity caused the leg to contract, but wrongly concluded that the electricity existed in the frog's muscles. Little did Galvani realize that in bringing together the iron, copper, and fluids in the frog's leg, he had hit upon the essentials of the chemical cell—namely, two dissimilar metals in contact with a chemically active solution.

When Volta heard of Galvani's experiments, he disagreed as to the source of the electricity. He set forth a different hypothesis in which he assumed that the electricity which affected the frog's muscles came from the metals used. In testing this hypothesis, Volta devised an experiment in which he placed a disk of copper on his table, then on top of that a pad soaked in sulfuric acid and water, and upon that a disk of zinc. He repeated this sequence many times until he had stacked up a large pile of alternate copper and zinc disks, each pair of disks separated by an acid-soaked pad. He then fastened a wire to the bottom disk of copper and another to the top disk of zinc. When he touched the wires together and then separated them, a fat spark was produced, giving evidence of an electric current. Here was the first real manufacture of electricity by chemical action. Volta improved on the electric pile and announced the voltaic cell in 1800.

To make a voltaic cell, put a plate of zinc and a plate of copper into a container of dilute sulfuric acid. Bubbles of hydrogen gas form at the surface of the zinc and the metal is eaten away, but nothing happens to the copper. If wires are then attached to the two metal plates and are properly connected to a *voltmeter*—an instrument for measuring voltage—the needle is deflected. This indicates an electromotive force caused by a difference of potential between the two plates. We notice, too, that bubbles of hydrogen form at the copper plate as well as at the zinc plate. To detect the electric current, we use an *ammeter*—a device that measures the intensity of the current in units called *amperes*. If the plates are large enough, sufficient current can be produced to ring a doorbell; then we can be sure that electricity is flowing. But where does it come from? How can zinc, copper, and sulfuric acid generate electricity?

Chemical action in the voltaic cell liberates electrons and drives them through a circuit. When sulfuric acid, $H_2(SO_4)$, is put into water, it breaks up into charged particles as follows: H^+, H^+, and $(SO_4)^{--}$. These charged particles, much too small to be seen, are called *ions*. When copper is immersed in the solution, nothing

happens; copper cannot react with the ions of sulfuric acid. When zinc is added, however, action begins at once. It is believed that atoms (the smallest unit particles of the elements) break away from the zinc plate and go into the solution. In doing so, each one leaves behind it on the plate two electrons. These electrons collect on the plate and give it a negative charge. Since negative charges repel each other, these excess electrons repel other electrons present all along the wire toward the copper plate.

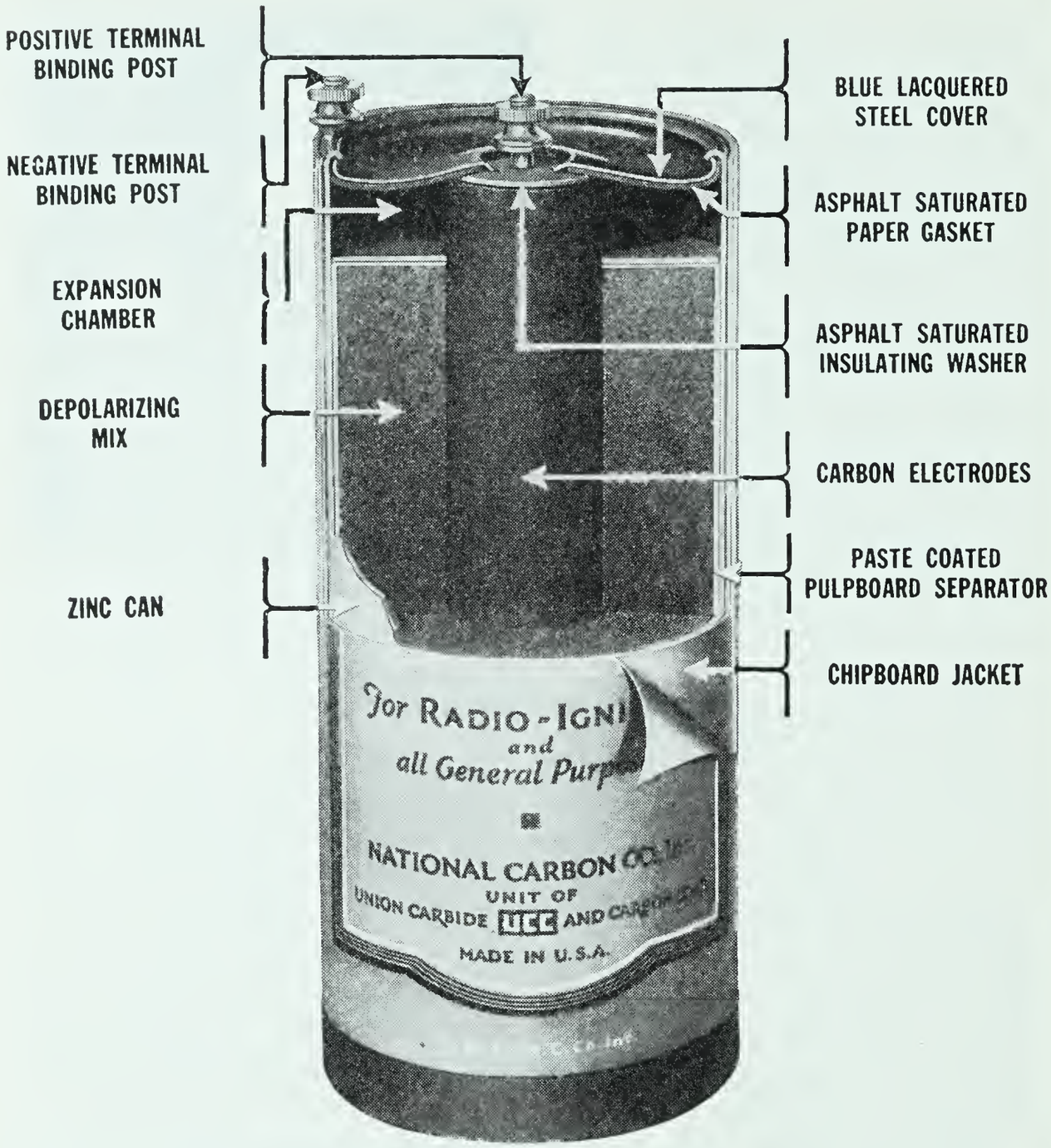


Chemical action in the voltaic cell liberates electrons and drives them through a circuit.

The zinc atoms that lose electrons go into solution as positive ions, Zn^{++}. Like charges repel each other. The H^{+} ions already in the solution therefore move over to the copper plate and give it a positive charge. Thus we have a potential difference: the zinc plate is negative and the copper plate is positive. By means of the connecting wire, electrons pass from the zinc to the copper. There they unite with hydrogen ions and produce hydrogen gas, which bubbles up through the liquid. *The flow of electrons is the electric current,* and the cell continues to transform chemical energy into electrical energy until either the acid or the zinc is consumed.

Before scientists knew anything about electrons, they agreed that the electric current flowed from plus to minus. This terminology is still in use in spite of our added knowledge that the electrons really flow in the opposite direction. You will understand, therefore, that we are merely following custom when we later refer to the current flow as being from positive to negative.

Dry cells are really wet cells. They operate on the same principle as the voltaic cell. The negative plate of the cell is a zinc cup in which the rest of the materials are placed. A carbon rod at the center of the cell serves as the positive plate. The zinc can is lined with absorbent paper soaked in ammonium chloride solution, and the space between it and the carbon rod is filled with a moist paste of ammonium chloride, manganese dioxide, and



Courtesy Union Carbide and Carbon Corporation

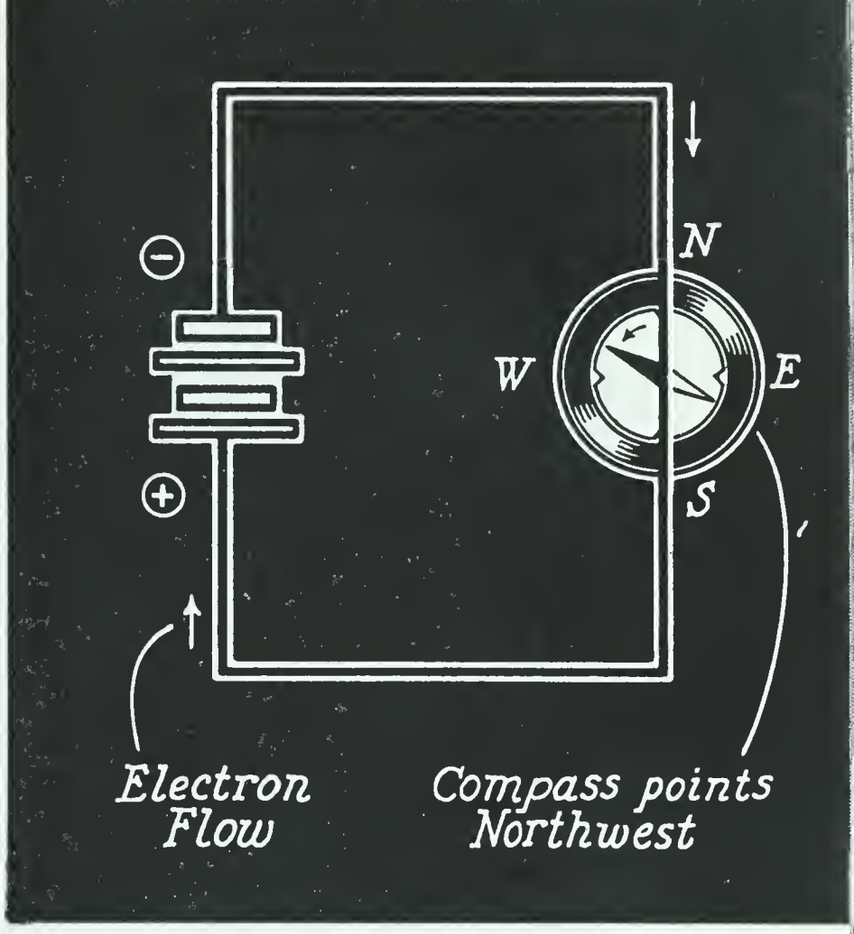
This diagram shows the inside of a dry cell.

fine carbon. If the cell were really dry, it would not work. To prevent loss of water by evaporation, the top of the cell is tightly sealed.

The ammonium chloride furnishes the ions necessary to the chemical action that delivers current. When the cell is supplying current, zinc is consumed as in the voltaic cell. In any cell in which hydrogen forms during use, tiny bubbles of the gas collect on the surface of the positive plate. This film of gas interferes with the transfer of electrons and causes the current to decrease. To prevent such an occurrence, manganese dioxide is included in dry

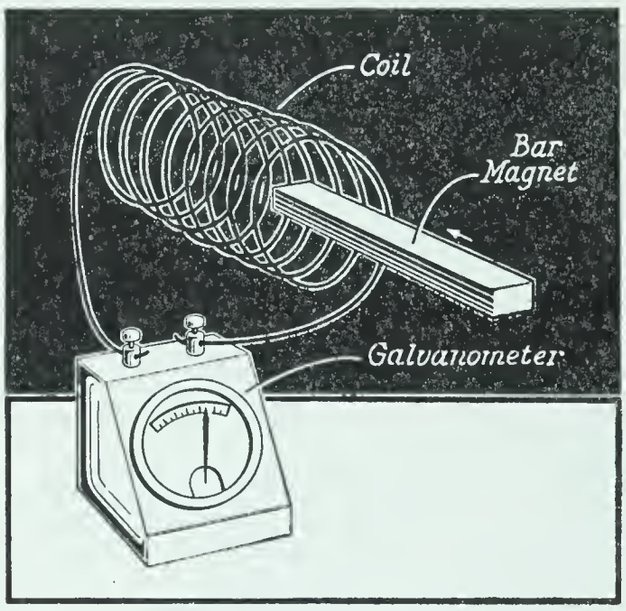
cells to oxidize the hydrogen to water. Dry cells should not be used continuously for long periods, because hydrogen then forms faster than manganese dioxide can remove it. They recover after excessive use if allowed to "rest" for a while.

Many different kinds of chemical cells have been devised, but dry cells are the most familiar and the most widely used. They are useful where small currents are needed for short intervals, as in ringing doorbells, in lighting flashlights, and in laboratory experiments. Newly made dry cells have an E.M.F. of about 1.5 volts and give a maximum current of about 30 amperes. Since they deteriorate rapidly whether used or not, their "shelf life" in a store usually ranges from twelve to fourteen months. In purchasing dry cells be sure to get fresh ones.

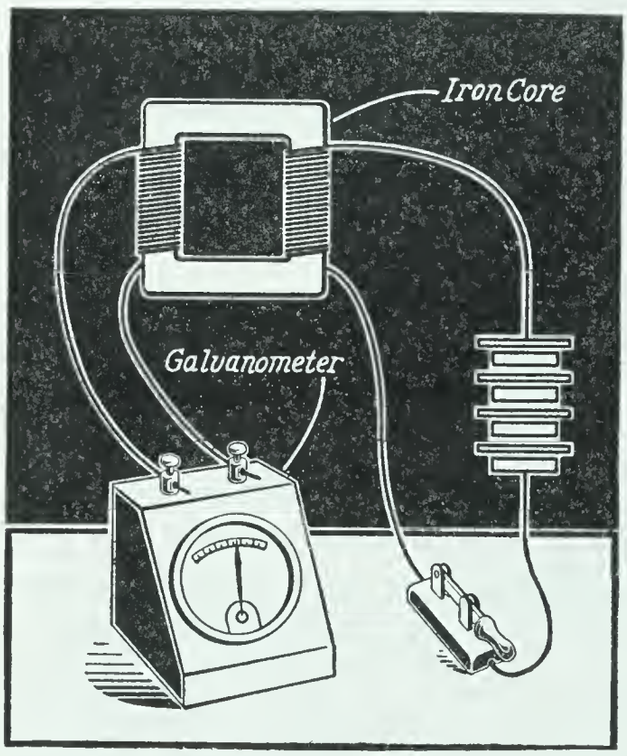


Electricity produces magnetism.

The development of the voltaic cell led to many discoveries about electric currents. The chemical cell did not furnish enough electricity to make possible the extensive use of electricity as we know it today, but it gave man a source of electric power suitable for many experiments. Scientists of all nationalities began to study the force of electricity, and their discoveries about it and about what it can do were truly amazing. At that time many people scoffed at these men and looked upon their experiments as forms of entertainment resembling magic. Others viewed their experiments with a "So what?" attitude, remarking, "It's interesting, but what good is it?" No one can predict the ultimate value or applications of new discoveries any more than he can foretell the future career of a newborn babe. In spite of many obstacles and much discouragement, these early scientists pursued their investigations. Today, all of us are reaping the benefits of their labors through the use of electrical devices that lessen drudgery, promote better health, give us new and better construction materials, increase our comfort and enjoyment, and benefit us in other ways too numerous to mention here.



This is a simple representation of the principle of electromagnetic induction discovered by Faraday. Can you explain the meaning of this diagram?

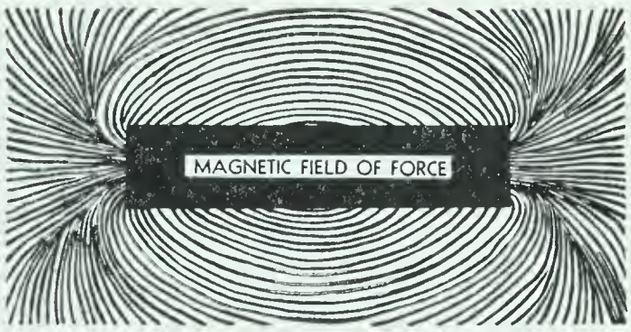


Current flows in the second coil whenever current is started or stopped in the first by opening or closing a switch.

• FROM WORK TO ELECTRICITY

In 1820, while giving a lecture on electricity, Hans Oersted, the Danish physicist, had before him a battery of voltaic cells connected by a wire. By chance he pushed a compass under the wire and was quick to notice that the needle was deflected. Oersted soon found that by passing an electric current through a wire held parallel to a magnetic needle, he could make the needle move. Electricity could produce magnetism!

"If electricity can produce magnetism, perhaps magnetism can produce electricity." So pondered Michael Faraday in England, and with this hypothesis he set to work on the problem of investigating the relationships between those two forces. By 1831, Faraday had discovered that an electric current could be produced by moving a bar magnet in and out of a coil of wire. The ends of the wire were attached to a *galvanometer,* an instrument used to detect small electric currents. He discovered, also, that if two coils of wire are wound on a soft iron ring, one coil being connected to a battery and the other to a galvanometer, current flows in the second coil whenever current is started or stopped in the first by opening or closing a switch. In this case, the magnetism that produces current in the second coil is furnished by the current that flows in the first.

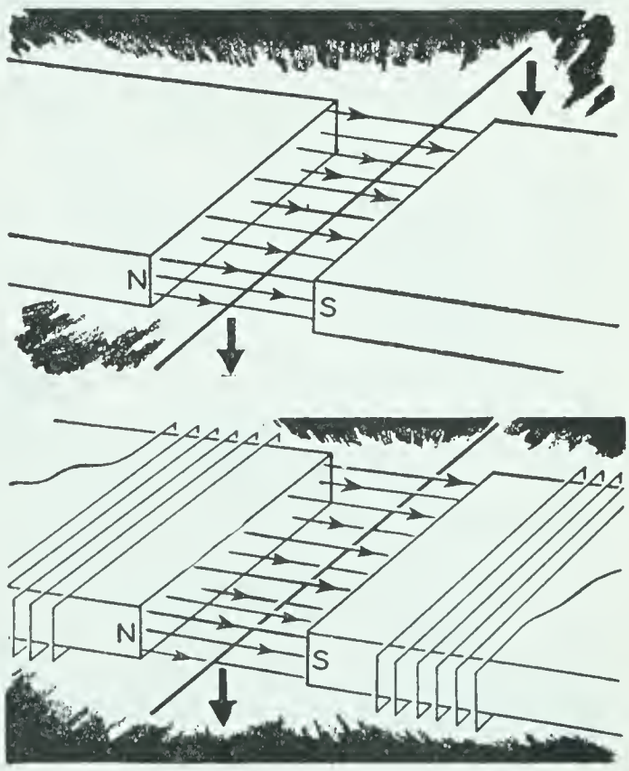


Courtesy General Motors Corporation

These and other experiments enabled Faraday to draw a conclusion that is one of the most important and far-reaching generalizations in the realm of electricity: *an electric current can be produced by causing a magnetic field and a conductor to move with respect to each other.* The conductor can cut through the magnetic field, or the magnetic field can move across the conductor. The magnetic field can be moved mechanically or electrically—it makes no difference.

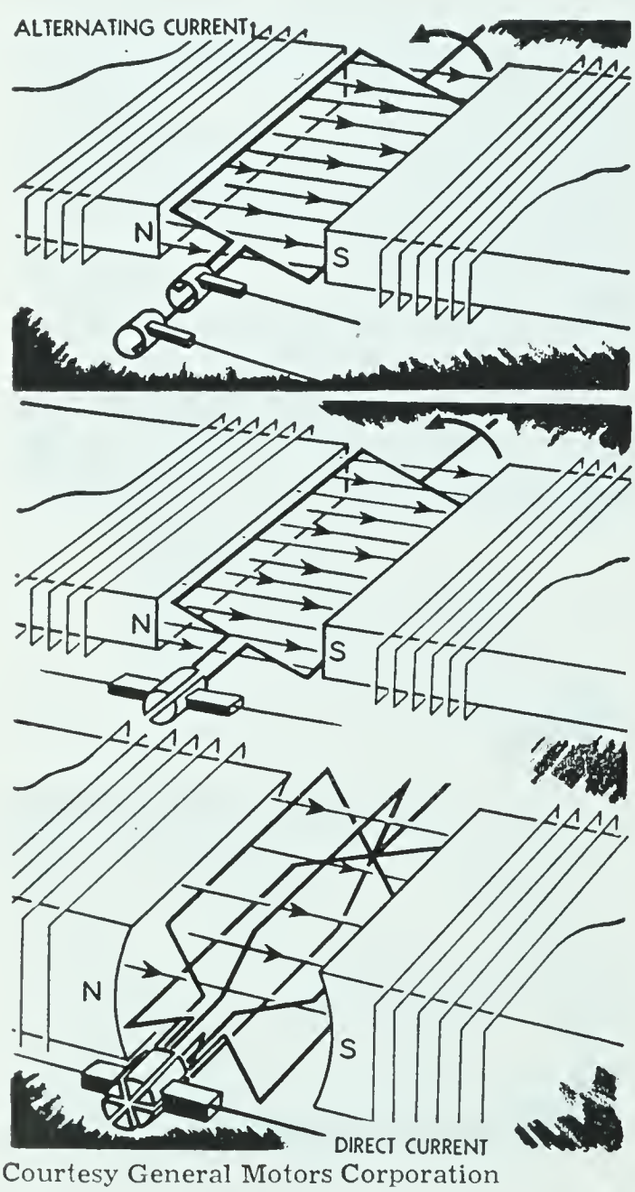
At about the same time, Joseph Henry in this country independently discovered many of the same things. Faraday and Henry deserve full credit for discovering the fundamental science principles upon which present-day electrical devices are based. With crude apparatus and commonplace materials, they carried on experiments that have made possible the industrial growth which has improved living conditions for all.

Faraday's discovery made it possible to transform work directly into electrical energy. When a conductor is moved through a magnetic field a voltage is induced in the conductor. If the ends of this conductor are connected to form a closed circuit, current flows. The magnetic field resists the motion of the conductor, and work is necessary to make the conductor cut through these lines of force. Energy and work are closely related. In accordance with the Principle of Conservation of Energy—energy cannot be created or destroyed—*the work done on the conductor is equal to the electrical energy induced in the conductor plus any loss of energy in the form of heat.* This basic science principle is seen at work in all types of generators from the simplest hand-driven machine to the huge commercial ones in electric powerhouses.



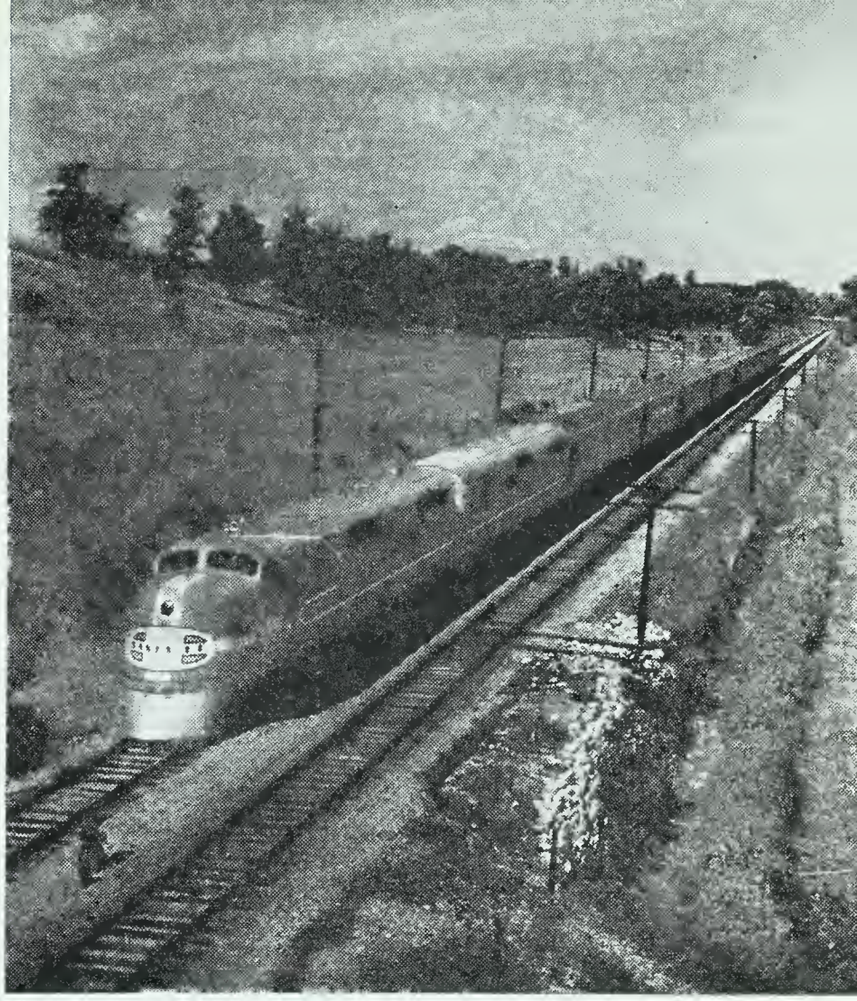
If a wire is moved down through a magnetic field, as shown in the illustration, a voltage is induced and current flows in the wire. Current flows only when the wire is moved up or down through the field, never when it is held stationary or moved parallel to the magnetic lines of force. We could go a step further and substitute an electromagnet for the two bar magnets. Since the electromagnet is generally stronger than bar magnets, the field is stronger, and more work is required to push the conductor through it—but we get a stronger current in the conductor.

To produce a continuous current, a device is needed which continuously cuts the magnetic field. Moving a wire *up and down* to cut magnetic lines of force gives alternate surges of current, first one way and then the other. Better than a straight wire is a loop of wire, mounted on an axis so that it can *rotate* in the magnetic field. Even this does not give a uniform current. In practical generators, many coils of wire, each consisting of a large number of loops of wire, are used. The coils are set at angles to each other, so that some coil is always cutting magnetic lines of force. Each coil contributes its share of the current at regular intervals. The rotating coils of wire, together with the iron core on which they are wound, make up the *armature;* the outside electromagnets are called the *field.*



Courtesy General Motors Corporation

What is next needed is a method of taking the current from the armature. If the ends of the wire in the armature are connected to two *slip rings* upon which two brushes rest, alternating current (A.C.) flows from the generator. If the ends are connected to two segments of a *split ring,* direct current (D.C.) flows from the generator. These methods of collecting the current are illustrated in the diagrams at the left.



Courtesy General Electric Company

A full-fledged electric-power plant mounted on wheels! In this modern streamliner, Diesel engines use oil as fuel and turn electric generators which furnish power to the electric motors that drive the wheels. Similar in appearance are the new steam-electric locomotives which are also fueled by oil to generate high-pressure, high-temperature steam for turbines connected to generators.

The magneto is a simple generator. The armature is an iron cylinder having two slots running lengthwise on opposite sides and wound with thousands of turns of insulated wire. The field consists of several permanent U-shaped magnets. By rotating the armature very rapidly, an alternating current of high voltage is obtained. Today magnetos are used mostly for providing sparks in gas engines. Formerly they were used to ring telephone bells and, in automobiles, to provide electrical power for ignition, lighting, and sounding the horn. The speed of the automobile engine determined how fast the armature rotated and thereby the strength of the current produced. When the engine was stopped, neither lights nor horn could be used. Since there was no storage battery or starter on the car, it was necessary to crank by hand. In the modern automobile, the storage battery furnishes current when the engine is stopped. It is charged by the generator when the motor is running. A direct-current generator is used, because only direct current can be used to charge a battery. The power required to drive the generator is supplied by the engine. Several devices, such as the cutout, current regulator, and voltage regulator, control the generator to prevent undercharging or overcharging the battery. In the same way, all trains, except those on electrified lines, use a combination of generators and storage batteries to provide electric power, which is used chiefly for lighting.

Commercial generators transform mechanical energy into electrical energy by the same basic principles that operate in simple generators. Almost all commercial electric power generated in the



The diagram shows the path of the magnetic stream between the poles of a direct-current generator.

United States is produced by generators driven by steam or moving water. The generators are attached directly to the shafts of the Pelton wheels, water turbines, or steam turbines, as the case may be. Great hydroelectric plants are located at Niagara Falls, Wilson Dam in Alabama, Norris Dam in Tennessee, Boulder Dam in Arizona, the dam across the Mississippi River at Keokuk, Iowa, and elsewhere. The Grand Coulee Dam on the Columbia River in Washington is the world's largest and will provide a source of electric power surpassing any yet tapped in the United States. Power plants located in cities throughout the country generally burn coal to produce steam and operate their electric generators by steam-driven turbines.

Many large hotels, department stores, theaters, and hospitals are installing Diesel-driven power plants, thus making themselves independent of outside power sources. Some locomotives and many ocean liners are now being driven by Diesel-electric or turbo-electric power plants. In rural sections of our country where commercial electricity is not available, many farms are equipped with light and power units driven by gasoline engines. Wind-driven generators are commonly seen in certain regions, especially the Midwest, where they provide power to keep radio batteries charged. In the Tuscany industrial region of northern Italy, one source of power is natural steam of volcanic origin. Twelve turbines are harnessed to 300 steam wells and generate 1,250,000 kilowatts of electrical power.

Direct current generators. In one type of commercial D.C. dynamo, several magnets are used on the same machine. The ends of these magnets are called *poles;* thus we have a four-pole, six-pole, or eight-pole machine. Coils of wire are wound around the poles, and when the current flows, they become strong electromagnets. The part of the machine which does not move is called the *stator.* The armature rotates and is called the *rotor.* The *drum-wound armature* has a large number of coils containing thousands of turns of insulated wire. When the armature rotates at high speed, these wires cut millions of magnetic lines of force each second, and alternating current at high voltage is induced in the

coils. It is converted into direct current by means of a *commutator* on the end of the armature shaft. The commutator consists of a number of wedge-shaped copper segments, one pair for each armature coil. These segments are insulated from each other and from the shaft with mica and are bound together to form a circle. The commutators and brushes of dynamos and motors alike should always be kept clean.

The field poles of a dynamo can be converted into magnets by using direct current from an outside source, such as a battery, but this plan is not employed in actual practice. The energy needed to magnetize the pole pieces is only a small per cent of the electrical output of the machine, and, in practice, current from the generator itself is used to produce the magnetic field. When starting a new dynamo for the first time, the field pieces must be magnetized by current from an outside source. When the machine stops, nearly all of the magnetism disappears, but enough remains to cause a little induced current when the dynamo is started again. As the generator gains speed, the field strengthens and the machine attains its maximum voltage very quickly.



Courtesy Westinghouse

To insure that a high-speed rotor for a powerful electric machine will operate perfectly, its surface is machined twice over in a lathe by skilled craftsmen after all windings are fitted and other work on it completed. The turbine generator of which this rotor is a part develops 30,000 kilowatts, equivalent to 40,000 electrical horsepower.

Alternating current generators. One type is almost identical with the drum-wound D.C. dynamo. It has a multipolar field that is stationary and a drum-wound armature that rotates. The direct current needed to magnetize the field poles is usually provided by a small direct-current dynamo called an *exciter*. If the strength of the magnetic field is kept uniform, the voltage of the alternator will be fairly constant. The alternating current produced in the coils of the armature is drawn off by brushes resting

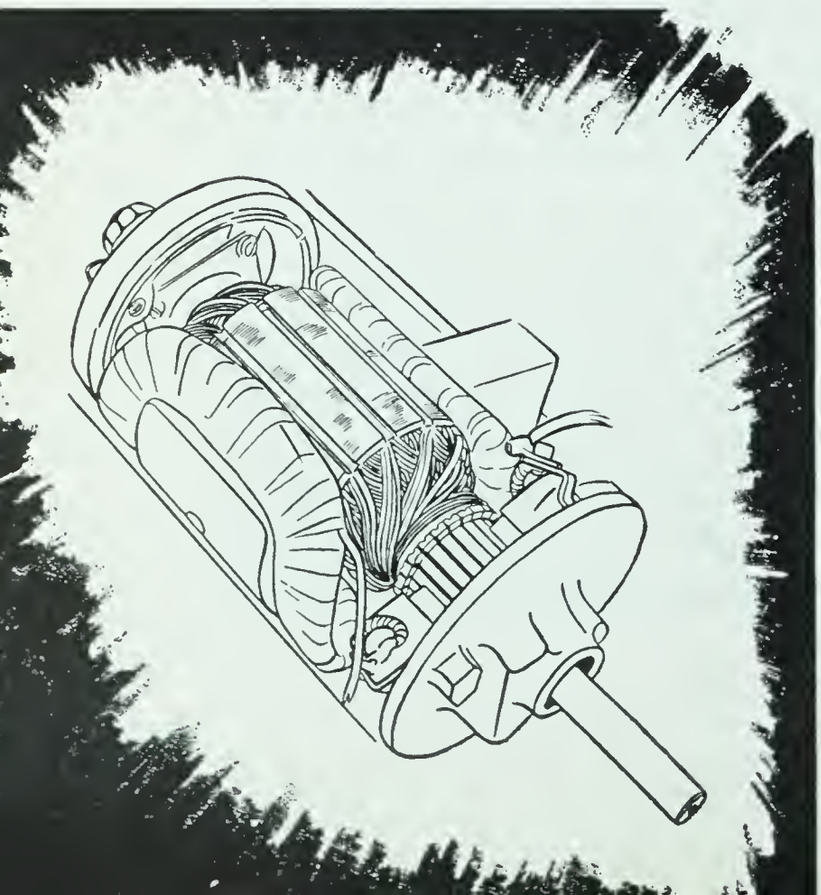
on two slip rings; hence it is also alternating current that flows in the main line. The more poles there are, the less rapidly the machine needs to be run to produce the desired kind of current. For ordinary purposes, a current of 60 cycles and 120 alternations per second is generally used.

In most commercial alternators, it is the magnetic field that rotates, while the coils of the armature remain stationary. The direct current required to magnetize the poles of the rotor is generally provided by a small direct-current dynamo and is fed into the coils by means of two slip rings. The ends of the wire wound on the stator lead directly to the external, main-line circuit. Since no brushes or slip rings are needed, the problem of insulation is not a difficult one, and current at very high voltages can be generated.

To Thomas A. Edison goes the credit for starting the electric light and power industry. Faraday and Henry discovered the fundamental principles on which electrical developments are based, but many other men helped put these ideas to work. Samuel Morse and Alexander Graham Bell applied electrical fundamentals to the problem of communication and developed the telegraph and the telephone, respectively. The electric-power industry, however, had to await the development of the electric light and the consequent need for large amounts of electric power distributed over wide areas.

This cutaway drawing is of an automobile generator. Where are the field coils, the armature, and the commutator?

Courtesy General Motors Corporation

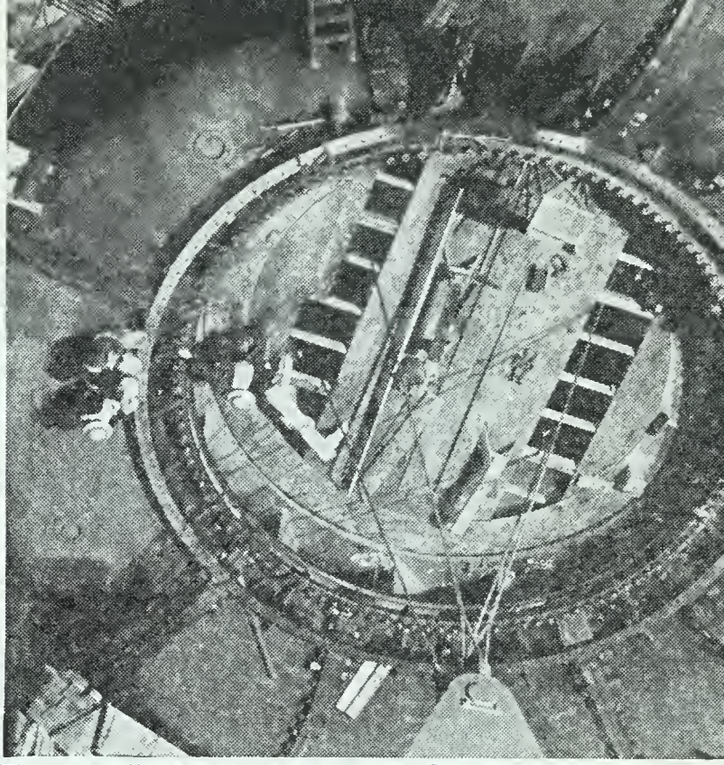


When Edison developed the first successful electric lamp, he realized that unless adequate sources of power were available, his light would continue as little more than a curiosity. Therefore, he built the Pearl Street station in New York City, which opened in 1882. It was the first central power plant in the world. Its lines served an area of approximately one square mile.

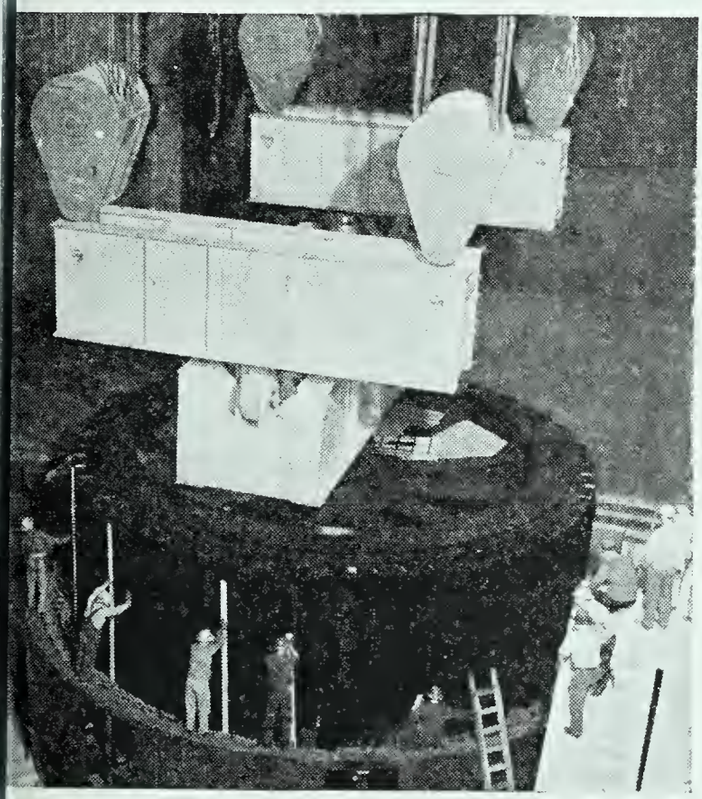
Since the opening of Edison's Pearl Street station, the power and light industry has grown by leaps and bounds. The total

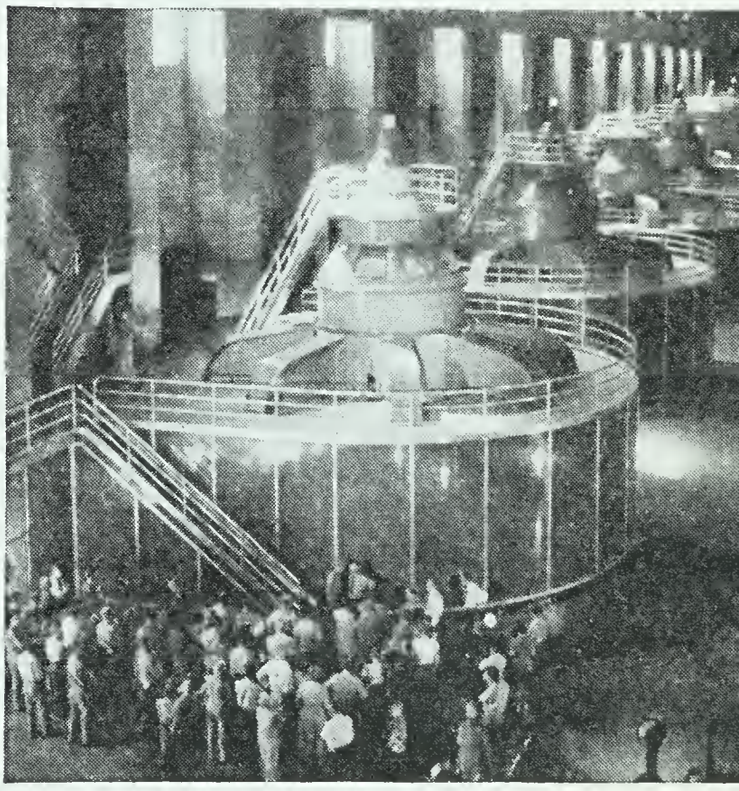


Grand Coulee Dam, the mightiest power project, is 4,300 feet long, 550 feet high, and 500 feet wide.



The scroll case above is for a 150,000 horsepower turbine, through which 2,025,000 gallons of water swirl per minute.

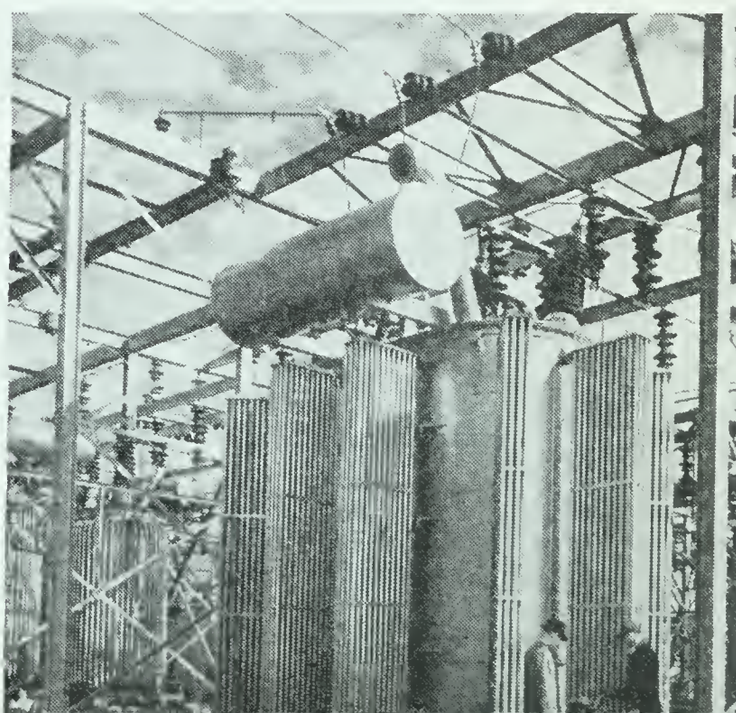




Above: The men are lowering a rotor into place for the 108,000-kilowatt generator at Grand Coulee Dam.

Above right: Huge generators are found in the Nevada wing of the Boulder Dam powerhouse.

Right: From the generators, electric power goes through huge transformers which change it to proper voltage for cross-country transmission.



Photos courtesy U. S. Bureau of Reclamation (top and center left and right); General Electric Company (bottom)

generating capacity of electric power stations increased from about 2,000,000 kilowatts in 1900 to 38,600,000 in 1939. One kilowatt equals 1⅓ horsepower, and 1 horsepower equals about 10¾ man power. Today, our electric generating plants produce power equivalent to the power of more than 550,000,000 men. We might inquire, "Who uses this power?" In 1939, the grand total of electricity consumers in the United States reached 28,750,000. They used 128,300,000,000 kilowatt-hours of electricity. Large industrial concerns took more than half of this output. The average domestic consumer used 900 kilowatt-hours. Even so, domestic consumption accounted for only about one-sixth of the total production for 1939.

Power plants have increased their efficiency with resultant savings to both the companies and the consumers. To produce 1 kilowatt-hour, it was necessary to burn about 3 pounds of coal in 1920 as against a little more than 1 pound today. The cost of a kilowatt-hour of electricity to all consumers—domestic and industrial—has dropped from an average of about 9 cents in 1912 to 4 cents in 1939. In general, the domestic consumer pays more a kilowatt-hour than does the industrial consumer. In 1939, the domestic consumer's bill averaged about 10 cents a day as compared with 8½ cents ten years before. The amount of electrical energy he received for his money, however, nearly doubled.

Many social and economic problems have grown up along with the electric power industry. The biggest problems are, Who shall control the industry? and What rates are fair to both producer and consumer?

Electricity has come to be a public utility as essential to modern life as fuels, water, and shelter. Therefore most people agree that the industry should be supervised by governmental agencies. Since 1906, almost all states have had public-utility commissions to make sure that consumers get electric power at a fair price and that the private producers receive a fair return on their capital investments. With the growth of holding companies, about a dozen large systems gained control of most of the electric-power industry in America by owning controlling stock in individual operating companies. These holding companies were unhampered by public regulation until the Public Utility Act of 1935 was passed by Congress to protect small stockholders and to bring about a lower cost for electricity.

During recent years, the citizens of many communities have obtained still lower rates by building municipal power plants. The

federal government has recently gone into the power business in the South, Southwest, and Far West. The intentions are to provide cheap power from hydroelectric plants and to establish "yardsticks" to determine the fairness of rates on power from other sources. Public tax money must be used to construct these plants, but many people believe that in the long run the savings in lower costs of electricity will more than pay the bill. Private companies, on the other hand, look upon this as unfair competition and fear that the plan will result in large losses to their stockholders. The government claims a further point in favor of its program by pointing out the value of these huge dams in flood control, control of soil erosion, irrigation, and navigation.

Exercises for Problem Study and Review

1. State the law of electrical attraction and repulsion. How do you explain the fact that such a long period of time was required to formulate this law?
2. What hypothesis is used by the scientist to explain the production of static charges and to interpret their effects?
3. Give proof that there are two kinds of frictional electricity.
4. What is meant by voltage? How is it comparable to water pressure?
5. In actual practice, how is a potential difference maintained?
6. Where do electrons come from in a voltaic cell? What makes them move? Where do they go?
7. What should you make certain of when you purchase a dry cell? How should dry cells be used? For what purposes are dry cells unsuited?
8. State the principle discovered by Faraday for generating an electric current.
9. How do D.C. and A.C. differ?
10. How is direct current produced by mechanical generators?
11. How is alternating current produced by mechanical generators?
12. Compare magnetism and static electric charges in as many ways as you can.
13. Why is Edison given the credit for starting the electric light and power industry?
14. How much does your local power company charge the domestic consumer per kilowatt-hour for electricity? How does this compare with the average cost in the United States in 1939?
15. What are the arguments for private ownership of the electric power industry? For public ownership?

Problem 3: How do we make use of the effects produced by the electric current?

• ELECTRICAL UNITS AND OHM'S LAW

The need for such units arises not only when scientists wish to measure electrical quantities or when practical electricians work with electrical circuits, but also when ordinary people want to understand what the labels on their electrical appliances mean and how their bills for electric power are calculated.

An understanding of three related units is basic to an understanding of electric currents. *The ampere.* Since the electric current is a stream of electrons, the amount of electricity transferred could be measured in terms of the quantity of electrons. One *coulomb* of electricity contains 6.3 billion billion electrons. This is a measure of quantity for electricity just as the quart and gallon are for water and gasoline. The rate of flow might be given as so many coulombs per second. In actual practice, the intensity, or rate of flow, of current is stated in *amperes.* An ampere is a rate of flow of 1 coulomb per second.

Ordinary electric lamps draw about 0.5 to 1 ampere. An electric iron, toaster, or grill requires from 5 to 8 amperes. Small electric motors used on household appliances operate on about 1 to 3 amperes. House circuits are usually limited to a maximum flow of 15 amperes. In commerce and industry, however, large motors may use 50 amperes and electric furnaces up to 10,000 or 12,000 amperes.

The volt. We have already learned that electricity flows only when there is a potential difference and that the unit of measurement for electrical pressure is the *volt.* Ordinary dry cells, when fresh, generate about 1.5 volts of electrical pressure. For household purposes, electricity is usually supplied at 110 to 120 volts. Voltages of 200,000 to 300,000 volts are often employed in long-distance transmission systems. The volt is defined as the electrical pressure necessary to cause a current of 1 ampere to flow through a resistance of 1 ohm.

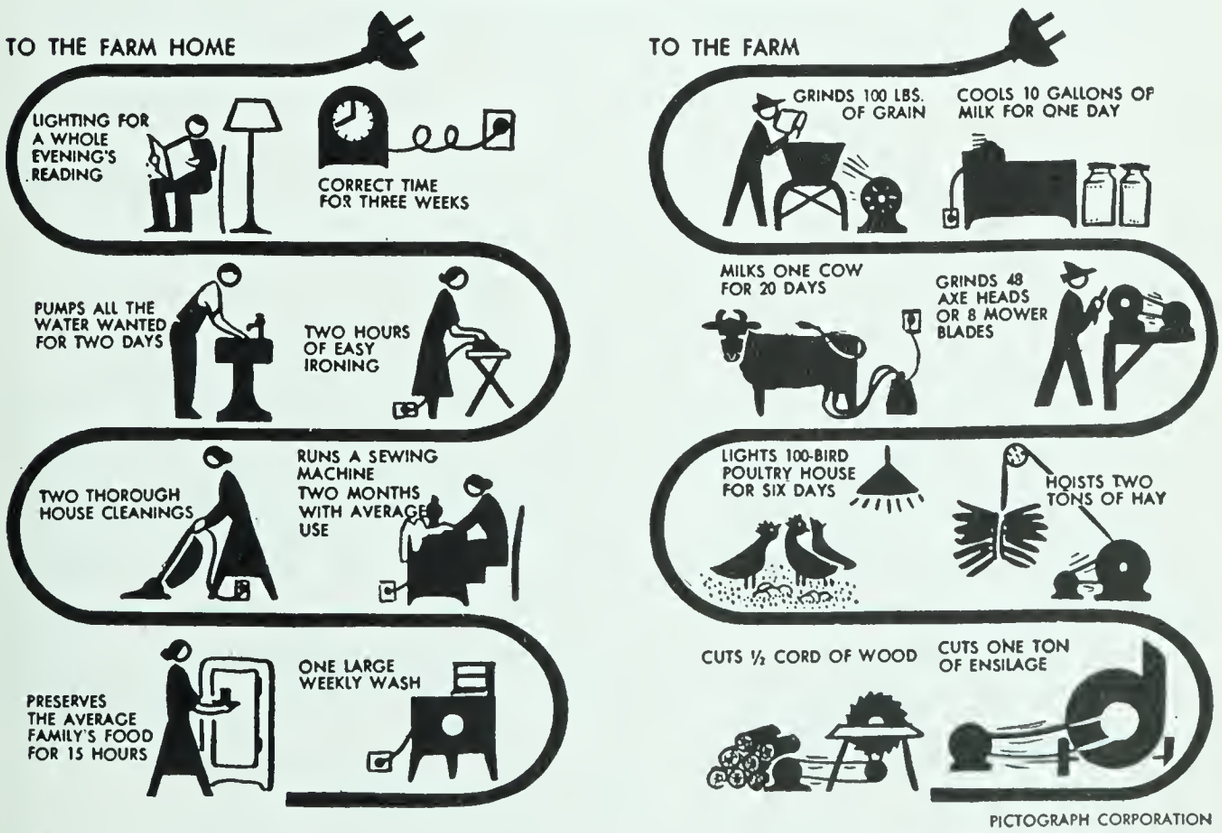
The ohm. All conductors offer some resistance to the flow of electricity through them. The unit of resistance is the *ohm,* and the resistances of different materials are determined by comparison with a standard. Incandescent electric lamps have resistances ranging from about 130 ohms for a 100-watt lamp to about 500

ohms for a 25-watt lamp. An electric grill or flatiron has a resistance of about 15 ohms. Electric motors offer small resistances ranging from 2 to 5 ohms.

Several factors affect resistance. Copper is commonly used to make wire for transporting electricity because it has the lowest resistance of the cheaper metals. Aluminum is next to copper, and its use for electric wire is increasing. Another factor, besides composition, that determines resistance is the length of the conductor. A wire 5 feet long offers five times as much resistance as 1 foot of the same wire. A third factor is diameter—the bigger the wire, the smaller the resistance. A wire twice the diameter of another wire has four times the cross-section area and only one-fourth the resistance for equal lengths. If a wire three times the diameter of another is used, it has nine times the cross-section area but only one-ninth the resistance. Thus we see that for wire of a given material, its resistance is directly proportional to its length and inversely proportional to its cross-section area.

Finally, resistance is affected by temperature. In general, metallic conductors increase in resistance as their temperatures rise. An ordinary electric lamp has a lower resistance when it is cold than when heated to incandescence. Carbon and conducting solutions behave just the opposite; that is, their resistance decreases as the

WHAT ONE KILOWATT HOUR MEANS



From Rural Electrification Administration

temperature rises. Sometimes an automobile engine "misses fire" when it is hot because of accumulated carbon deposits on the spark plugs. The hot carbon decreases electrical resistance and prevents the building up of the high voltage necessary to produce a "hot spark."

Ohm's law states the relationship among amperes, volts, and ohms. In the distribution of water, two things govern the amount transmitted by a given pipe in a given time: (1) the pressure with which the water is forced through the pipe; (2) the resistance offered by the pipe to the flow of water. Similarly, two factors determine the amount of electricity that will flow through a given circuit in a given time: (1) the electrical pressure or voltage; (2) the resistance offered by the circuit to the passage of electrons.

These relationships were first studied experimentally by Georg Simon Ohm, a German physicist, and by him stated in a law which now bears his name. Ohm's law tells us that *the intensity of current in any part of an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance.* Ohm's law can be expressed more clearly as follows:

$$\text{current} = \frac{\text{electromotive force}}{\text{resistance}}, \text{ OR } \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

By using standard abbreviations as follows, current intensity (I), voltage or electromotive force (E), and resistance (R), we have

$$I = \frac{E}{R}.$$

If two values in Ohm's law are known for a particular situation, the third can be calculated, for by simple mathematical treatment we see that if $I = \frac{E}{R}$, then $R = \frac{E}{I}$, and $E = IR$.

In the case of electricity, power is the rate at which energy is consumed or transformed. The unit of electrical power is the *watt;* it is the power developed when 1 ampere flows at a pressure of 1 volt. The power in a circuit is calculated by multiplying volts by amperes; in accepted abbreviations, the formula for power is $W = EI$.

The watt is a small unit, and for many purposes a unit 1,000 times as big is used; it is the *kilowatt.* The number of kilowatts may be found as follows:

$$\text{kilowatts} = \frac{\text{volts} \times \text{amperes}}{1{,}000}$$

One horsepower is equal to about 746 watts, or about three-fourths of a kilowatt. One kilowatt is equal to about 1⅓ horsepower.

To calculate how much energy we consume, we must know the rate at which it is consumed and for how long. Electric bills are calculated on the basis of units called *kilowatt-hours*. If we use five 100-watt lamps for 4 hours, the electrical energy transformed into heat and light is $5 \times 100 \times 4 = 2{,}000$ watt-hours, or 2 kilowatt-hours. If the electric rate is 8 cents per kilowatt hour, the cost is 16 cents. Thus we see that

$$\frac{\overbrace{\text{volts} \times \text{amperes}}^{\text{watts}} \times \text{time}}{1{,}000} = \text{kilowatt-hours, and}$$

$$\text{kilowatt-hours} \times \text{rate} = \text{cost.}$$

• FROM ELECTRICAL ENERGY TO HEAT

Regardless of the purpose for which we use an electric current, the efficiency of the process is always less than 100 per cent because of the production of unwanted heat. Even in the transmission of electricity by wires, heat is developed. This causes energy losses to the company, and it frequently occurs to such a degree in the wiring of buildings that it becomes a fire hazard. If properly controlled in such devices as electric toasters, grills, irons, and stoves, the transformation of electrical energy into heat is a clean and convenient, though usually somewhat expensive, method of obtaining heat.

The heating effect of the current can readily be demonstrated by attaching a short length of fine copper wire to the terminals of a dry cell. The wire will become red-hot and melt. The source of the heat is thought to be the friction encountered by the electrons as they move through the wire.

A definite quantitative relationship exists between electrical energy and heat. Since the source of heat from electricity is resistance to the flow of electrons, we would expect that of two conductors, the one of greater resistance would develop the larger amount of heat. This is true providing two other factors are equal: (1) the amperage; (2) the time. It is logical to expect the amount of heat developed to increase with the length of time the current flows, but we would hardly predict correctly the effect of altering the intensity of the current. Experiment shows that if



Courtesy General Electric Company

The electric range is easy to regulate and use and does not make the kitchen uncomfortable on hot days. Note how the heating element lifts up for cleaning and replacement.

the current through a given resistance is doubled, the amount of heat produced is four times as great; if the current is made three times as strong, the amount of heat developed in a given time is multiplied by nine. In other words, the heat energy developed in any conductor is proportional to the square of the current.

The laws governing the transformation of electrical energy into heat may be summarized in a single statement as follows: *the heat energy developed in any conductor is directly proportional to the square of the current in amperes, to the resistance of the conductor in ohms, and to the time the current flows.* If we express the time in seconds and multiply the product by 0.24, the final answer will be the amount of heat in calories. Using standard abbreviations, we have the formula:

$$\text{heat in calories} = I^2 \times R \times t \times 0.24$$

Suppose we use an electric toaster of 22 ohms resistance on a 110-volt line. How much heat is developed during ten minutes' use? By Ohm's law we see that $I = \frac{E}{R}$; hence the toaster will draw 5 amperes.

Heat in calories $= (5 \times 5) \times 22 \times 600 \times 0.24 = 79{,}200$ calories. This is enough heat to warm about one quart of water from room temperature to its boiling point.

The heating effect of the current is widely applied in the home. In typical home heating appliances, the actual heating element is a coil of high-resistance wire composed, usually, of iron, nickel, or nickel-chromium alloy, and arranged to concentrate the heat produced. Such wire provides the necessary resistance in a com-

pact space and, in addition, does not melt or oxidize and corrode very much at the high temperatures attained.

Electric grills, toasters, percolators, irons, and the like are convenient, clean, and ordinarily not too expensive to operate. Electric stoves, on the other hand, are generally expensive both to buy and to use. In some places, a reduced rate is provided to consumers of electric power used for stoves and water heaters. Increased efficiency can be obtained by proper and careful operation, by the use of flat-bottomed utensils which are large enough to cover the entire heating element, and by using cooking utensils with black bottoms. What is the reason for this?

Electric stoves have several advantages and a few disadvantages. Good ones cook almost as rapidly as gas stoves, and they contribute much less to overheating the kitchen. The hazard of carbon monoxide poisoning or of gas explosions and the danger due to open flames are completely eliminated. On the other hand, electric stoves introduce to some extent the hazard of shock and the possibility of short circuits, which may result in electrical fires. The cost of replacing worn-out heating elements is high.

The heating effect of the current is widely applied in industry. One type of electric furnace commonly used in industry operates on the resistance principle. If the material to be melted is a conductor, it is placed in a suitable vessel, and a large current is introduced. The heat generated soon causes melting. Or the material, if a nonconductor, is packed around a carbon rod through which a large current flows, producing sufficient heat to melt the

Two forty-ton direct-arc furnaces are shown in operation. Arrows point to the carbon arcs. What are the advantages of producing steel in electric furnaces?

Courtesy *Electrical World*





Courtesy *Electrical World*

Metal is being poured from a small electric furnace of the resistance type. Where are the heating coils located?

The steel girders of a modern skyscraper are here being joined by means of electric-arc welding, thus eliminating the ear-splitting racket of riveting.

Courtesy *Electrical World*

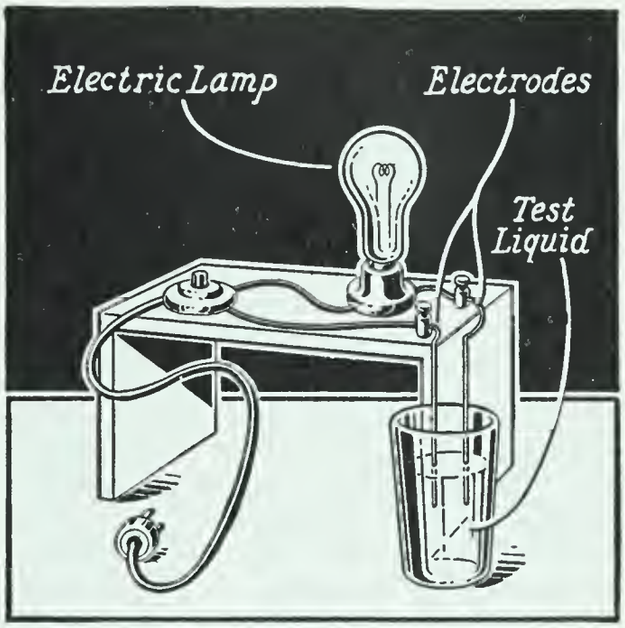


charge. In another type of resistance furnace, a coil of resistance wire or ribbon is wound on a core of some high-melting material, and whatever is to be heated is placed inside the coil. Resistance furnaces provide temperatures up to about 2,000 degrees centigrade. In another type of furnace, an electric arc passing between very large carbon rods is arranged to heat the material to be melted while contained in a crucible. The arc furnace enables man to obtain a temperature of about 3,500 degrees centigrade. Electric furnaces are used in the manufacture of graphite, carborundum, calcium carbide, high-grade steel, and special steel alloys.

In electric welding, the pieces of metal to be joined are placed together, and a large current is sent through the junction. The resistance at the point of contact is so great that sufficient heat is generated to weld the metals together. Electric welding is being increasingly used in the fabrication of automobile bodies; steel racks, stands, filing cabinets, and the like; and even in steel construction work, such as bridges and buildings.

Electric lamps as used today contain a high-resistance filament of tungsten, and the heat produced by the flow of current causes the filament to be-

come incandescent. At first, however, electric lighting was done by means of the carbon-arc lamp. The heat generated by the passage of current is sufficient to vaporize some of the carbon and cause it to become incandescent. The hot tips of the carbon rods and the luminous carbon vapor between them form the most brilliant source of light yet produced by man. Carbon-arc lamps are still used to a considerable extent for theatrical spotlights and motion-picture projectors, but for almost all other purposes they have been replaced by the gas-filled tungsten lamp. A more detailed account of how man obtains light from electricity is given in Unit Seven.

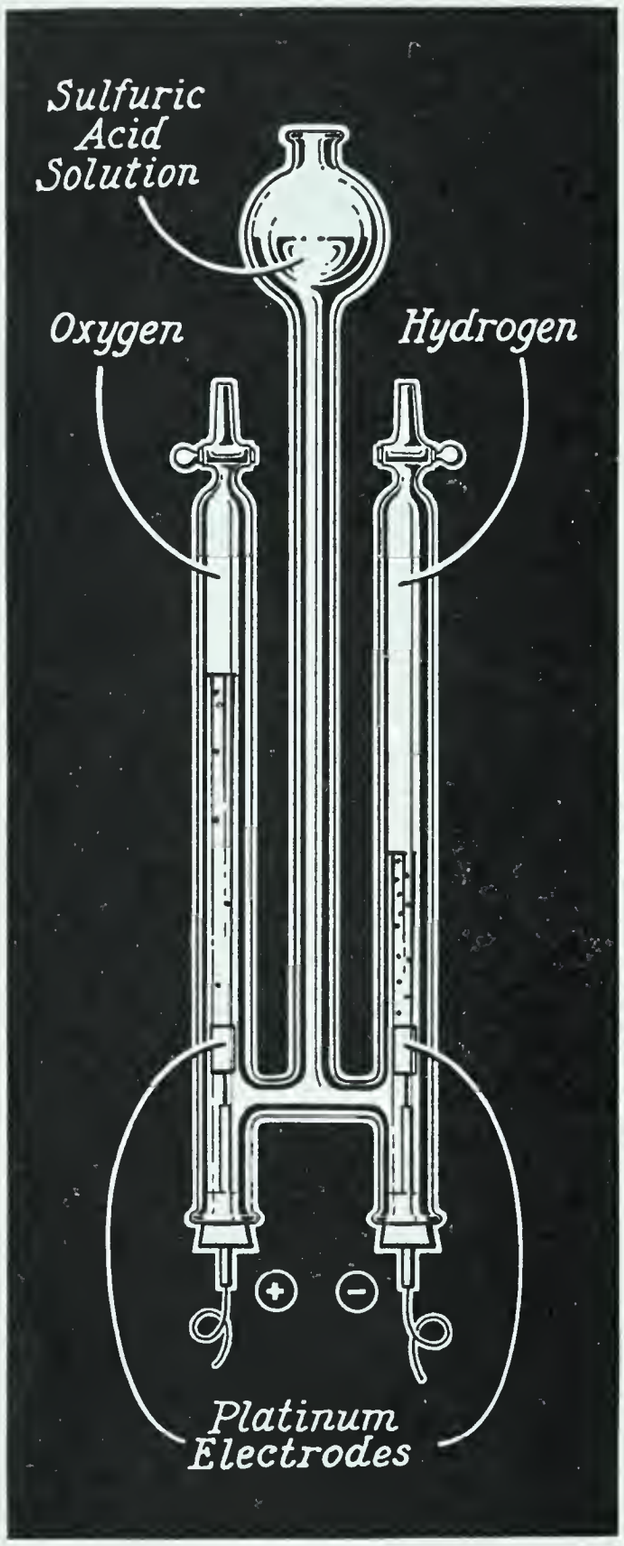


The glowing of the lamp indicates that the test liquid is a conductor of the electric current.

• FROM ELECTRICAL ENERGY TO CHEMICAL ENERGY

We test liquid materials for electrical conductivity by using an apparatus similar to that shown in the drawing. The plug is connected to the regular 110- to 120-volt line. If the lamp glows when the wires (electrodes) are in contact with the liquid and the switch is closed, then that liquid is a conductor of electricity. If it glows very brightly, we say it is a good conductor; if it glows faintly, we say it is a poor conductor. If the lamp does not glow at all, we say the material is a nonconductor. A substance whose solution is a conductor is called an *electrolyte;* other substances are called *nonelectrolytes.*

When distilled water is tested, we find it to be a nonconductor. Alcohol, benzene, and carbon tetrachloride are in the same class. Sugar and glycerin also are classed as nonelectrolytes, for, when dissolved in water, their solutions do not permit the current to flow—the lamp does not glow at all. Opposite results are obtained, however, when *acids, bases,* and *salts* are dissolved and tested. Typical acids are hydrochloric, nitric, sulfuric, and acetic acids. Acetic acid is the one which makes vinegar taste sour. Sodium chloride (table salt), copper sulfate, and potassium nitrate are typical salts; while sodium hydroxide (household lye), ammonium



hydroxide (household ammonia water), and potassium hydroxide are examples of bases. These substances are all electrolytes and form conducting solutions.

Whenever current flows through a conducting solution, chemical change always occurs. If an apparatus similar to that shown in the drawing is filled with water containing some sulfuric acid and a low-voltage direct current, as from a storage battery, is passed through the solution between the electrodes, a chemical change results. Oxygen forms at the positive and collects in the tube above, while hydrogen comes off at the negative. This is one commercial method of preparing these two gases.

Ions, as we have already learned, play an important part in the production of electric currents by chemical action. They are equally important in chemical reactions brought about by the passage of an electric current through a conducting solution.

When sulfuric acid is put into water, its molecules split apart into two kinds of charged particles—positive and negative ions:

$$H_2(SO_4) \rightarrow H^+, H^+, (SO_4)^{--}$$

When the current is turned on, the positive hydrogen ions are attracted to the negative electrode where they gain electrons and form hydrogen gas, which bubbles up through the solution:

$$2H^+ + 2e \rightarrow H_2 \uparrow$$

At the same time, the negative sulfate ions are attracted to the positive electrode where they give up their excess electrons and form neutral (SO_4) groups:

$$(SO_4)^{--} - 2e \rightarrow (SO_4)^{\circ}$$

These neutral groups cannot remain as such, however, and they immediately decompose some water molecules, uniting with the hydrogen to form more sulfuric acid and freeing the oxygen, which also bubbles up through the solution:

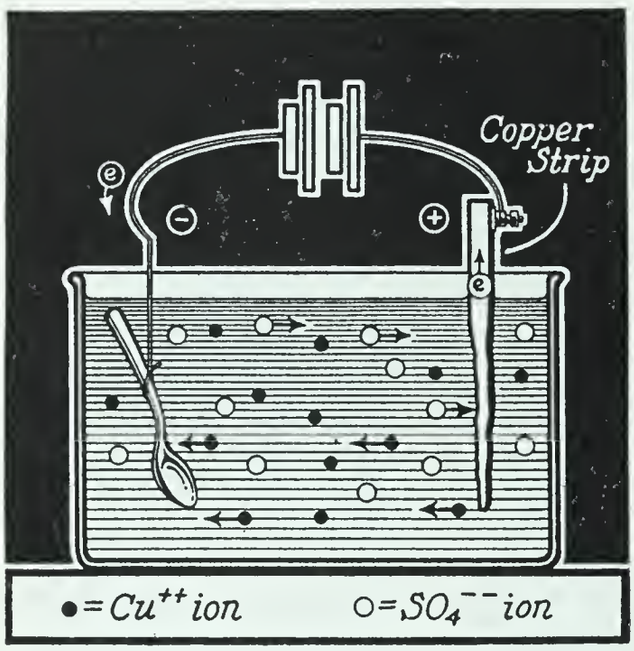
$$2H_2O + 2(SO_4)^{\circ} \rightarrow 2H_2(SO_4) + O_2 \uparrow$$

The newly formed sulfuric acid splits into ions, and the same process continues until the last molecule of water is decomposed, or until the current is turned off. Such chemical action is called *electrolysis.*

Electrolysis is widely applied in the production of useful materials. Oxygen and hydrogen are both obtained to some extent by the electrolysis of sulfuric acid solution as just described. The oxygen can be used for oxyacetylene welding, while the hydrogen is useful for inflating balloons, in the manufacture of substitutes for lard from cottonseed, cocoanut, and peanut oils, and as a gaseous fuel in the oxyhydrogen torch.

The electrolysis of sodium chloride (table salt) solution produces some very essential chemical products. Hydrogen is evolved at the cathode, chlorine is liberated at the anode, and sodium hydroxide (lye) is formed in the solution. Chlorine is a greenish-yellow gas which is used both as a preserver and a destroyer of life. It has a characteristic disagreeable odor and when breathed in any large quantity produces a marked irritation of the membranes lining the respiratory passages, resulting in coughing, inflammation, and, in extreme cases, suffocation and death. Thus is chlorine gas used as a "killer" during warfare.

Ordinarily, however, chlorine serves mankind in beneficial ways. Fully three-fourths of the people on the North American continent drink water which has been chlorinated because of the germicidal action of chlorine. For the same reason, sewage and the water of many swimming pools are chlorinated to kill the bacteria which spread disease. These measures have enabled man to conquer almost completely typhoid fever and other water-borne diseases. Chlorine is used to a great extent as a bleaching agent in the textile and paper industries. The sodium hydroxide formed during the



What changes would be necessary if the plating were to be done with silver instead of copper?

electrolysis process is essential to the manufacture of soap and is also used in refining petroleum.

By means of electrolysis, aluminum and magnesium are extracted from their ores. These two metals are essential to the modern lightweight alloys used in aircraft and other structures where it is desired to combine strength and light weight.

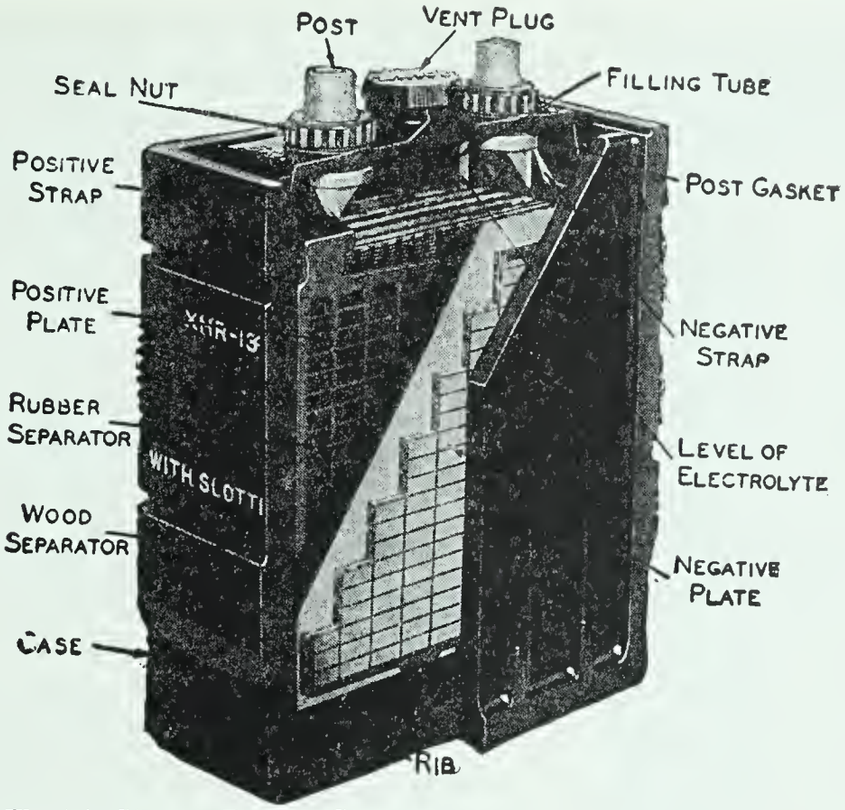
Electrolysis is applied in electroplating and electroforming. *Electroplating* is essentially the act of placing a thin coat of one metal upon the surface of another by a chemical reaction in solution, brought about by the passage of an electric current. Usually the purpose is to make the plated object more resistant to corrosion or to give it the appearance of a more costly article.

If an article is to be copper plated, for example, it is attached to the cathode of the cell, a strip of copper is attached to the anode, and both are immersed in a solution of copper sulfate, $Cu(SO_4)$. When copper sulfate is dissolved in water, it splits into ions, as shown in the diagram:

$$Cu(SO_4) \rightarrow Cu^{++}, (SO_4)^{--}$$

When the current is turned on, the Cu^{++} ions go to the cathode where they gain electrons and become neutral copper atoms. The copper atoms deposit as a thin film on the surface of the object to be plated. At the same time, $(SO_4)^{--}$ ions move to the anode and unite with atoms of the copper anode to form more copper sulfate. This splits into ions and the process repeats.

Electroplating with metals other than copper is done similarly. The objects to be plated are attached to the cathode. A bar of the plating metal (nickel, silver, chromium, etc.) is attached to the anode, and the solution is made with a soluble compound containing the plating metal. A direct current must always be used. For best results in commercial electroplating, it is essential to have



Courtesy The Electric Storage Battery Company

Details of an electric storage battery are shown above. Arrows point to its most important parts.

the object thoroughly clean, to use a solution of correct composition and concentration, and to regulate voltage and amperage accurately.

Electroforming is another example of depositing metal by electrolysis. One of its most important applications is in the reproduction of engravings and type used in the printing of books. A wax impression is made of the original material as set up by the typesetter. The surface of the wax is made a conductor by applying a thin coating of graphite, and this is then copper plated as just described. The wax is removed by boiling water, the copper shell is filled in with lead to give it strength, and the result is a *plate* used for repeated printing.

Electrolysis is also applied in the storage battery. In 1860, an alert French investigator was engaged in a study of the gas bubbles which form on the plate surfaces of chemical cells and stop their action. He was using a cell composed of plates of lead covered by dilute sulfuric acid, and connected to a voltaic cell. After the lead cell had been connected for some time, the experimenter, while changing connections, attached the wires from the lead cell to a galvanometer. Much to his surprise, the galvanometer needle was strongly deflected. He was quick to realize that here was a new type

of battery that could work two ways. When current was sent into the battery, electrical energy was changed to chemical energy, or, as we now say, it was charged. After the battery was charged, it could be used as a source of current. The chemical energy could be changed back into electrical energy. This is the principle of the storage battery used in automobiles. Many men have since contributed to make the storage battery a dependable source of starting power for the automobile.

Plates for automobile batteries are made of lead grids in which a paste of lead oxide is pressed. They are dipped into a solution of sulfuric acid, and a direct current of electricity is sent through them. When thus charged, the oxide is changed to brown peroxide of lead on the positive plates and to gray, spongy lead on the negative plates.

Each cell of the storage battery is made up of a number of alternate positive and negative plates separated, usually, by insulating wood or hard rubber sheets. All of the positive plates are connected and form the positive element; likewise, the negative plates are joined together and form the negative element. These plates are totally immersed in dilute sulfuric acid solution contained in a hard rubber or plastic cell. Each cell has thirteen or more plates, the capacity of the battery to deliver current being determined by the number. On a cold morning when starting the engine, an automobile battery may deliver 300 or more amperes.

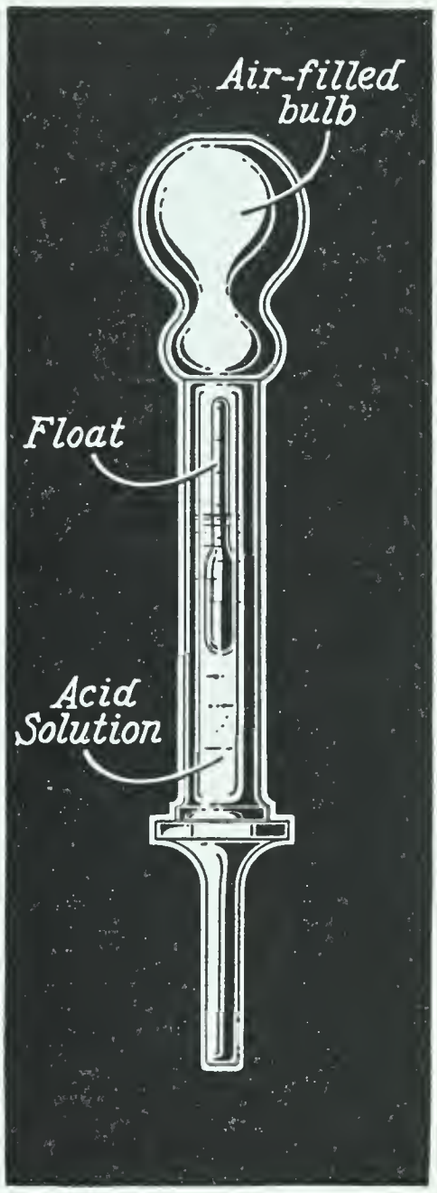
Each cell gives about 2 volts, regardless of the number of plates. The number of cells joined in series determines the voltage of the battery. Three such cells are used to obtain the 6-volt battery used on practically all passenger automobiles. Storage batteries are rated according to their capacity in ampere-hours, which is based on a continuous discharge for an 8-hour period. A 120-ampere-hour battery will deliver a steady current of 15 amperes for 8 hours.

Chemical action within the battery during use changes the composition of the plates and of the solution. When current is drawn from the battery, the lead peroxide and the spongy lead both change to lead sulfate. Water is produced and sulfuric acid is consumed, thus forming a more dilute solution.

As the plates approach the same chemical composition, the flow of current decreases. The battery becomes "run down" and needs to be recharged. During charging, chemical action within the battery is reversed. The lead sulfate again becomes lead peroxide and spongy lead, and the concentration of the acid increases.

Intelligent care prolongs the life of a storage battery. The gen-

erator charges the battery whenever the automobile engine is running at sufficient speed, but if the battery is used excessively, it may be necessary to remove it and have it charged at the service station. The density of the sulfuric-acid solution in the battery, as determined by a hydrometer, indicates the extent to which the battery is charged. It is especially important to keep the battery fully charged during cold weather. A discharged battery will freeze at a temperature a little below the freezing point of water, but a fully charged battery will withstand temperatures down to 90° below zero Fahrenheit. If batteries are allowed to become greatly discharged or to stand for a long time in a discharged condition, the lead sulfate on the plates may crystallize, causing buckling and warping of the separators. This does permanent damage to the battery.

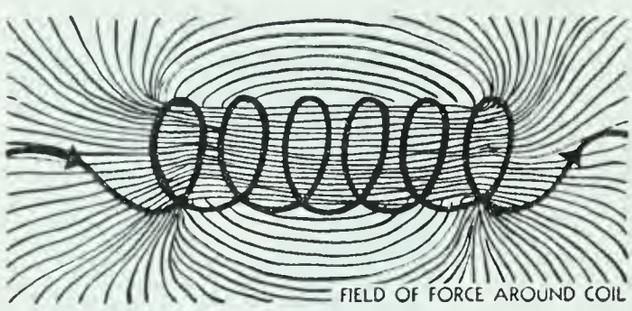


How does the hydrometer indicate the extent to which a storage cell is charged?

The level of the liquid in the battery should be kept above the top of the plates by supplying distilled water about once a week in summer and once every two weeks in winter. Use only distilled water or, if this is unobtainable, clean rain water. Only a battery expert should ever add acid or fresh acid solution to a battery. The value of "battery dopes" advertised for restoring or reviving run-down batteries is severely questioned, to say the least, by the National Bureau of Standards. They have no proved value and often do permanent harm to a battery that has some possibilities for repair.

• FROM ELECTRICITY TO MAGNETISM

The magnetic effect is the most widely used effect of the electric current. Oersted, you will recall, discovered that any wire or other conductor carrying a current of electricity is surrounded by invisible whirls of magnetism called the magnetic field. To obtain a



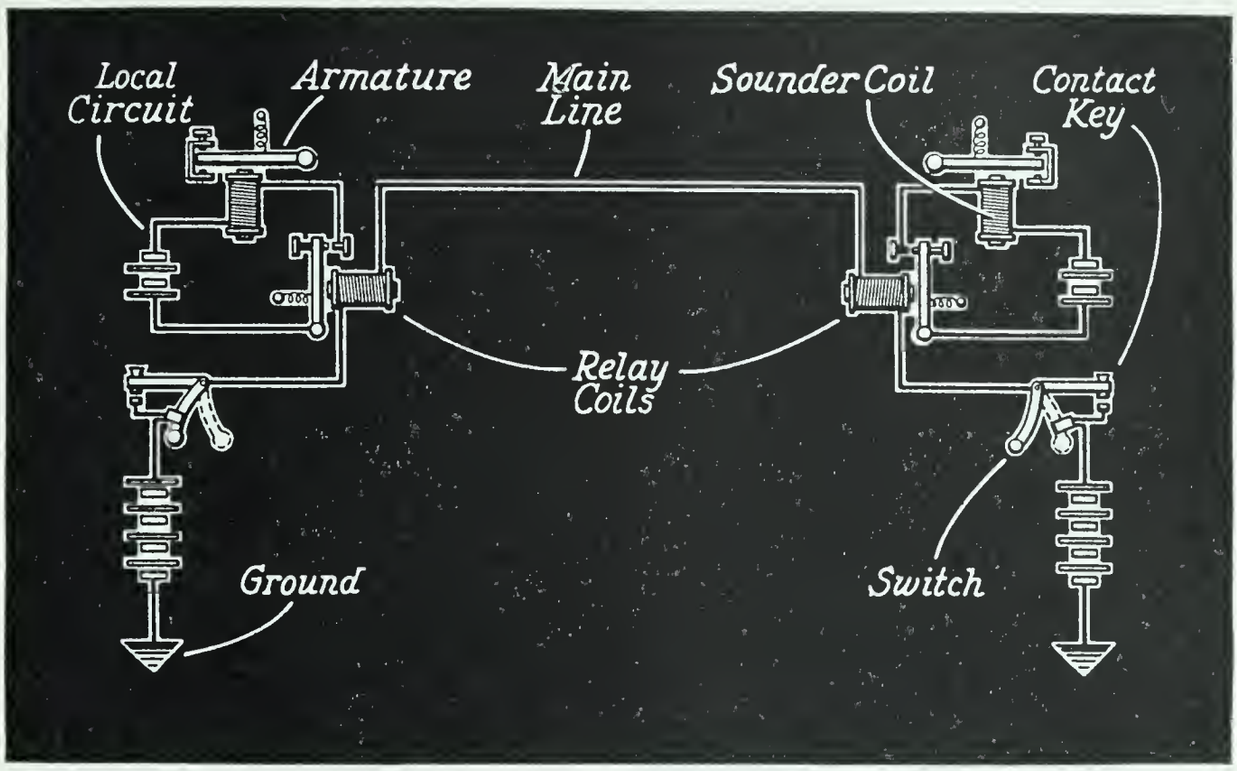
Courtesy General Motors Corporation

more intense magnetic field from a small current, the wire is wrapped to form a coil. When a bar of iron or steel is placed inside the coil, the magnetic field is concentrated and becomes still stronger, because iron and steel offer less resistance than air to the magnetic lines of force and also because the bar becomes magnetized and its magnetic lines of force add to those of the coil. Such a coil of wire with an iron core is called an electromagnet. One end of an electromagnet becomes a north pole and the other end a south pole, just as in bar magnets.

A simple rule enables us to determine the direction of the magnetic field about a straight wire carrying a current: *Grasp the wire with the right hand so that the thumb points in the direction of the current (+ to −); then the fingers will curl around the wire in the same direction as the magnetic field.* This rule, known as the *thumb rule,* also enables us to determine which end of an electromagnet is the north pole and which is the south: *Grasp the coil of the electromagnet with the right hand so that the fingers curl and point in the same direction that the current flows through the coil; then the thumb will point to the north pole of the electromagnet.* This is because magnetic lines of force are considered to come out of a magnet at the north pole, return through the air, and enter at the south pole. If, on the other hand, one has found by means of a compass the direction of the magnetic field around a straight wire carrying current or has discovered which is the north pole of an electromagnet, the thumb rule can be applied to determine the direction of the current in each case. How can this be done?

An electromagnet is a part of almost every electrical machine. This is partly due to the strength of electromagnets, but more so to the fact that their magnetism can be controlled accurately and easily. The magnetism lasts only as long as the current flows. When the current is turned off, the soft-iron core loses almost all its magnetism. If the core were made of hard steel, it would retain nearly all its magnetism and become a permanent magnet.

Applications of the electromagnet are found in the magnetic hoist, the electric bell, the telephone, and the telegraph; in electric motors and generators; and in electrical measuring instruments

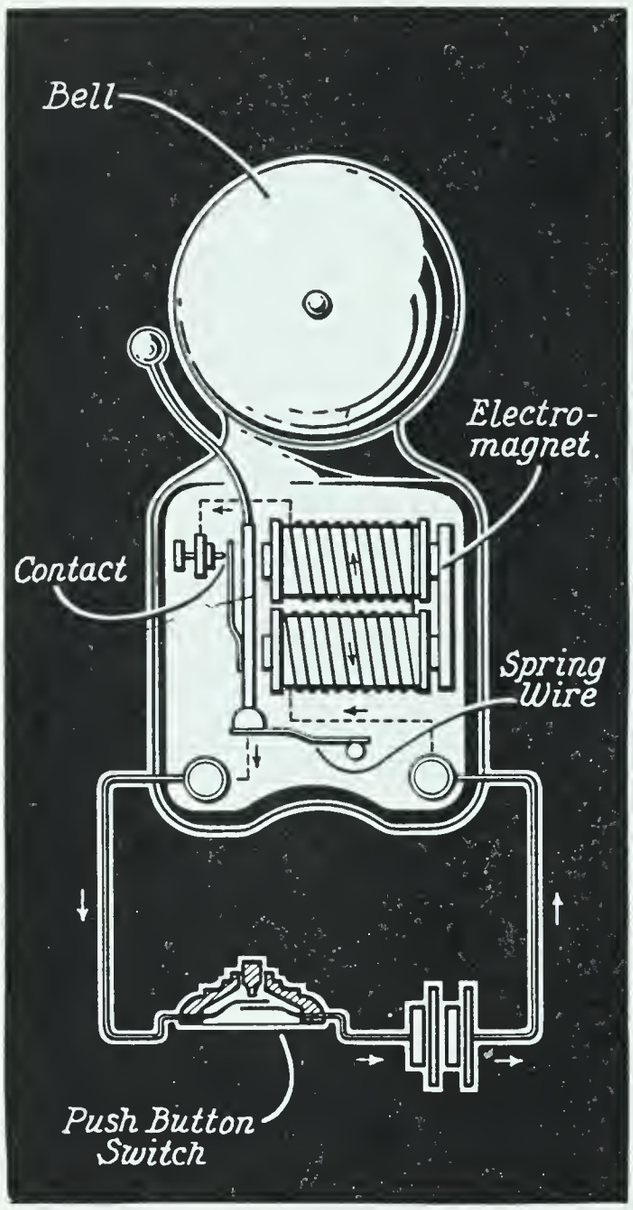


Trace the steps in sending a message from the station at the left over the long-distance telegraph line to the station at the right.

like the galvanometer, voltmeter, watt-hour meter, and ammeter.

The magnetic hoist. A laboratory model of a lifting magnet demonstrates the tremendous force that can be exerted by an electromagnet. With a good model, nearly 100 pounds can be lifted by using a single dry cell as the source of current. It is often said that the strength of an electromagnet depends on the number of *ampere turns* in the coil. An electromagnet having 1,000 turns of wire carrying 4 amperes is equal to one having 2,000 turns of wire carrying 2 amperes—both have 4,000 ampere turns. Modern magnetic hoists are capable of lifting as much as 200 pounds per square inch of pole face, and they are used to lift all sorts of iron and steel —scrap iron, steel rails, kegs of nails, and even locomotives.

The telegraph. A telegraph circuit is shown in the diagram. When the key is pressed down, it allows current to flow from the battery through the key and through the relay coil. The circuit is completed through the earth by grounding the battery and through the main line. The relay is really a very sensitive electromagnetic switch. It has a coil of many turns of fine wire. The armature is very light and is held away from the electromagnet by a delicate spring. When the main-line circuit is closed by pressing the key, the feeble current passes through the many coils of the relay and produces enough electromagnetism to pull the



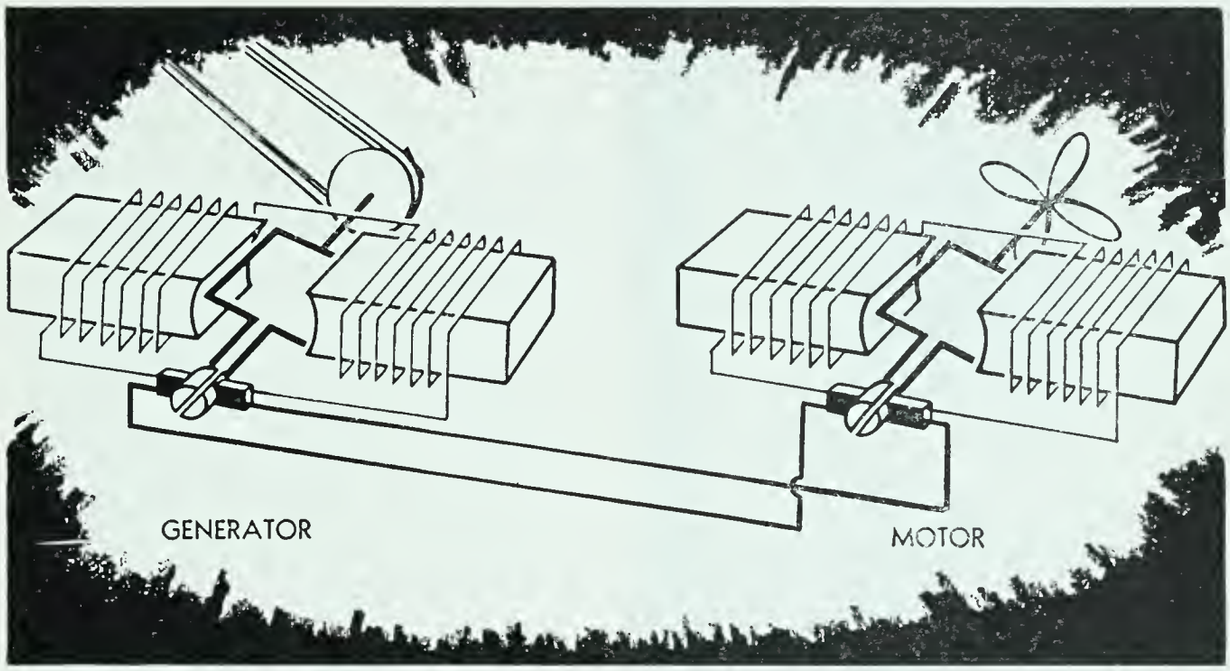
Why does the bell ring as long as the push button is held down?

armature against a setscrew. This action closes the local circuit, and a strong current from the local battery goes through the sounder.

When current flows through the coil of the sounder, the iron core becomes a magnet and draws down the armature against the lower setscrew. Upon releasing the key, the circuit is broken, the current stops flowing, and the magnetism disappears. This releases the armature, and the spring pulls it away so that it clicks sharply against the upper setscrew. There is a difference in tone between the clicks against the two setscrews, and the operator interprets the short and long time intervals between clicks as dots and dashes, which are later translated into letters according to code.

Modern telegraph systems show remarkable advances over those of a generation ago. Sending telegraph messages today is like typewriting by remote control. The operator at one end of the line sends the message by typing it on a machine, while a similar machine at the other end automatically types it on a strip of gummed paper. The strip is cut and pasted on the familiar blank sheets of the telegraph company.

The electric doorbell. This device is very similar to the telegraph both in construction and operation. When the push button is pressed, the circuit is complete, and the current flows from the battery as shown by the arrows. Electromagnetism attracts the armature to which the tapper is attached and causes it to move. In so doing, the tapper hits the bell and breaks the circuit at the contact point. When the circuit is broken, the electromagnet ceases to attract the armature, and the spring pulls it back to its original



Courtesy General Motors Corporation

The D.C. generator is a reversible machine. What does this mean?

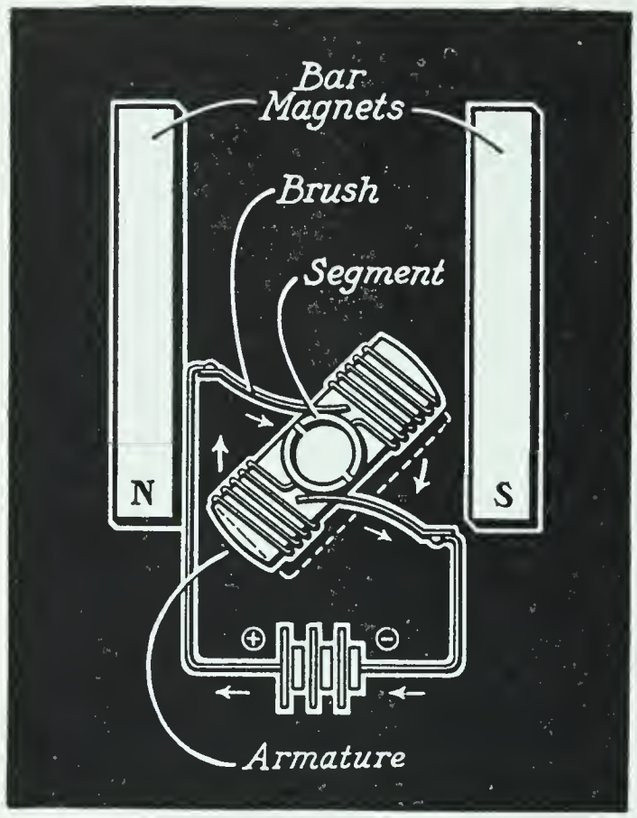
position. This closes the circuit again, and all steps are repeated. Thus the tapper vibrates or rings the bell as long as the circuit is closed at the push button.

• FROM ELECTRICITY TO WORK

In 1873, the Belgian electrical engineer, Z. T. Gramme, was supervising the installation of several of his newly developed direct-current generators for the Vienna Industrial Exposition. Two generators were installed side by side and were to be driven by steam engines. The first was complete and running, the second standing idle waiting to be connected to its engine. A workman happened to attach the wires from the moving generator to those of the idle one. At once the second generator began to rotate. Gramme, standing near-by, looked for a moment at the unexpected happening and realized that his generator was also a motor when current was sent into its windings.

Thus it was discovered that *the D.C. generator is a reversible machine.* When used as a generator, the armature is forced to rotate in a magnetic field and mechanical energy is transformed into electrical energy. The reverse of this occurs in the motor. We bring electrical energy to it and in return get mechanical energy which can be used for doing work.

The principle of the electric motor is based on magnetic attraction and repulsion. A study of the next diagram will reveal how the simple motor operates. Current from the battery enters the arma-



This diagram explains the principle of the simple electric motor.

ture windings through one fixed brush and commutator segment and returns to the battery through the other segment and brush. When current flows, the iron core on which the windings are wrapped becomes an electromagnet. If you trace the flow of current in the diagram and apply the thumb rule, you can determine which end of the armature is a north pole and which a south. Attraction and repulsion occur between the poles of the armature and the poles of the field magnets. These forces cause the armature to turn.

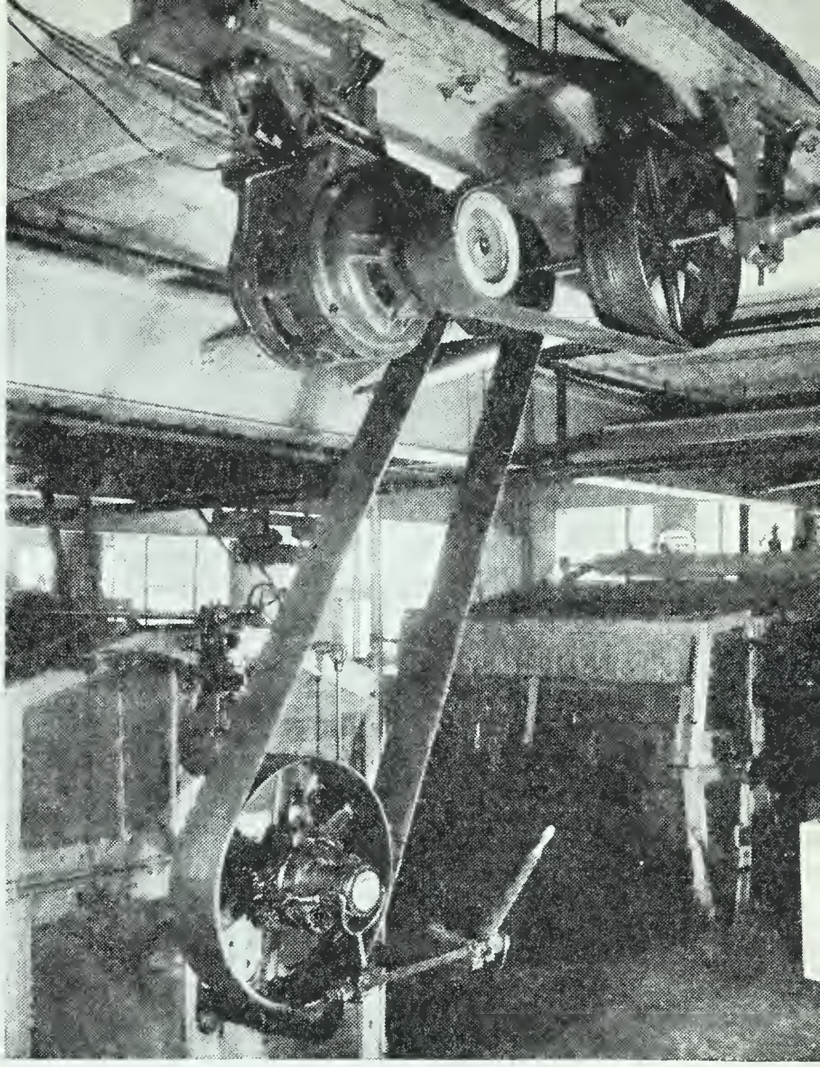
If current continued to flow through the windings in the same direction, the same end of the armature would always be a north pole. Rotation would cease when this pole came nearest the south pole of the field. This possibility is avoided by the use of stationary brushes and rotating segments. The current in the windings reverses just as the poles of the armature come nearest the unlike poles of the field; therefore the magnetic polarity of the armature reverses, and attraction and repulsion occur as before. Inertia of the armature carries it past "dead center."

The principle of magnetic attraction and repulsion is applied in all motors. There are many types of motors, and they vary in construction. Instead of using permanent magnets for the field, electromagnets are generally provided. The armature is usually made by winding wire in slots cut lengthwise in an iron cylinder or drum. The armature thus consists of a core having a large number of loops of wire. When current flows through the loops, magnetism is produced, which, by its reaction to the magnetism of the field, produces rotation.

Series motors. A series motor is wired so that all the current passes through both the field and the armature. Such motors slow down under heavy loads but have the advantage of exerting tremendous force when running slowly or when starting. They are

therefore used in trolley cars and trolley busses, electric automobiles, cranes, and other heavy machinery where the load is connected to the motor at all times. Another advantage of the series motor is that it will run on either direct or alternating current. Small series motors are used for such purposes as driving electric fans and vacuum sweepers. They are often marked "A.C. or D.C." on the label.

Shunt motors. A shunt motor is wired so that the current divides, part going through the armature and part through the field. Under varying loads the shunt motor maintains a nearly constant speed. This is the chief reason why this type is more widely used than any other kind of D.C. motor. It is especially useful for driving machinery in shops.



Courtesy E. F. Houghton and Company

This motor is mounted up out of the way. A smooth flow of power is transmitted by means of leather belting to the machine below.

Synchronous motors. If an A.C. generator is connected to a source of alternating current and is set going at the same speed as the alternator supplying the current, it will keep on running as a motor. It is called a synchronous motor because its rotation must be synchronized with that of the generator furnishing the current. Some electric clocks are run by very small synchronous motors. Their accuracy depends on the regularity of the 60-cycle current.

There are many reasons for the extensive use of electric motors. They are small and compact for the amount of power they develop, and they are available in a wide range of sizes and horsepower ratings. When compared to steam engines, gasoline motors, or Diesel engines, they are much cleaner and quieter. By means of electricity and electric motors, the transmission and use of power in shops and factories have been made safer, quieter, and more economical. Instead of shafts and belts for conveying power directly to the machinery from a steam engine, today the steam engine usually runs a generator, the electric power is sent by wires to all

parts of the plant, and electric motors utilize the power in running machines wherever desired.

Another advantage of electric motors is their high efficiency. The mechanical energy obtained in return from a motor as compared with the electrical energy consumed by the motor is very high—often 80 per cent to 90 per cent. The difference between the input and the output represents energy lost as heat. However, motors should not heat to a high temperature even when in constant use. When buying home appliances driven by electric motors —vacuum sweepers, for example, look for the safety seal of the Underwriters' Laboratory of the National Board of Fire Underwriters. If they have approved the motor, minimum safety features have been incorporated into its design and construction, and it is not likely to overheat.

Exercises for Problem Study and Review

1. State Ohm's law, giving the factors involved, the units for measuring these factors, and the standard abbreviations for the units.
2. Does Ohm's law apply when an electric fuse "burns out"? Explain.
3. What combination of factors would induce you to buy an electric range in preference to a gas range for your kitchen?
4. Give several examples of the importance to industry of the heating effect of an electric current. How could these jobs be accomplished otherwise?
5. Why does water make the use of electricity and electrical appliances more dangerous?
6. With only salt, water, electrical energy, and suitable apparatus, how many useful products can be obtained? How are these products used?
7. Why is chlorine described as "both a destroyer and a preserver of life"?
8. What rules should be observed in using and caring for a storage battery?
9. Why does a storage battery "run down"? Why cannot dry cells be recharged?
10. The ends of a horizontal copper wire running in a north-south direction are connected to a dry cell. A compass needle held above the wire points toward the west. In which direction is the current flowing in the wire?
11. Explain: "The strength of an electromagnet depends on the number of ampere turns."
12. Make as long a list as you can of devices which make use of electromagnets.

13. Examine the labels on the electrical devices in your home which are operated by electric motors. Tabulate the types of motors and the characteristics of each, including the number of amperes, horsepower, revolutions a minute, etc.

14. What makes an electric motor run?

15. An electric toaster has a resistance of 20 ohms. How much current will it draw if used on a 120-volt line?

16. When a small electromagnet is connected to three dry cells connected in series, the current through it is 0.3 of an ampere. What is its resistance?

17. What voltage is needed to send a current of 0.5 of an ampere through an electric lamp of 230 ohms resistance?

18. The label on an electric toaster reads "550 watts." If used on a 110-volt line, what current does it draw? What is its resistance?

19. An electric lamp of 150 ohms resistance is operated on a 120-volt line. How many calories of heat does it give off in 1 hour?

20. Which has the higher resistance, a 100-watt lamp or a 60-watt lamp? Explain.

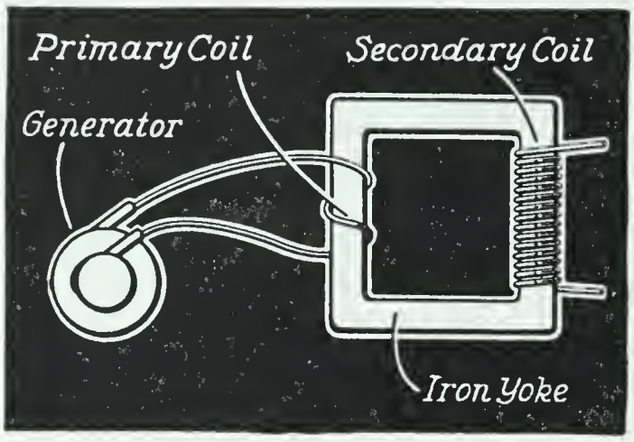
21. If the electric rate averages seven cents a kilowatt-hour, what is the cost of operating the toaster in Question 15 for 1 hour? The lamp in Question 19 for 10 hours?

Problem 4: How does man transmit and control electricity?

• FROM ONE VOLTAGE TO ANOTHER

Alternating-current electricity is used much more extensively than direct-current electricity for power in homes and factories. This preference is due to the ease with which large alternating currents at low voltage can be changed into small ones at high voltage, or vice versa. The heat which develops in the transmission line as electricity meets resistance to its flow is a total loss of energy. Less electrical energy is lost in this way when the amperage is low and the voltage high than when the amperage is high and the voltage is low. Naturally, power companies adopt the arrangements which hold to a minimum the loss of their product during delivery.

Why a small current at high voltage is more economical to transmit is better understood when one re-examines the formula which enables us to calculate the amount of heat in calories developed as current flows in a conductor of known resistance. The formula, you will recall, is $I^2 \times R \times t \times 0.24$, with I the current in amperes,



The transformer is a voltage changer.

R the resistance of the conductor in ohms, and t the time in seconds. For a conductor of given resistance, the heat developed during a given time interval is thus directly proportional to the *square* of the current. If other factors are held constant, the line loss is four times as great when a current of 2 amperes flows as when a current of 1 ampere flows, and nine times as great when a current of 3 amperes flows, and so on.

Transformers make it possible to transmit electrical power at low amperage and high voltage. The voltage transformer, like the generator, illustrates the principle that an induced voltage is set up in a coil of wire whenever there is a change in the number of magnetic lines of force passing through the coil. In the diagram on this page, note that the transformer consists of an iron core on which are wrapped two coils of wire, one having few turns and the other many. The coils are insulated from each other and from the iron core. One coil of the transformer is connected into a circuit carrying alternating current. As the current surges through the coils, first in one direction and then the other, it produces magnetism which also alternates in direction, as you can see by applying the thumb rule. The magnetic lines of force flow through the iron core and cut the windings of the second coil. This is the condition necessary for an induced voltage, as discovered by Faraday.

The coil in which the current is induced is called the *secondary*, while the one to which current is supplied is called the *primary*. The electromotive force induced in the secondary compares with the electromotive force in the primary as the number of turns of wire in the secondary coil compares with the number of turns in the primary coil. This may be expressed as an equation:

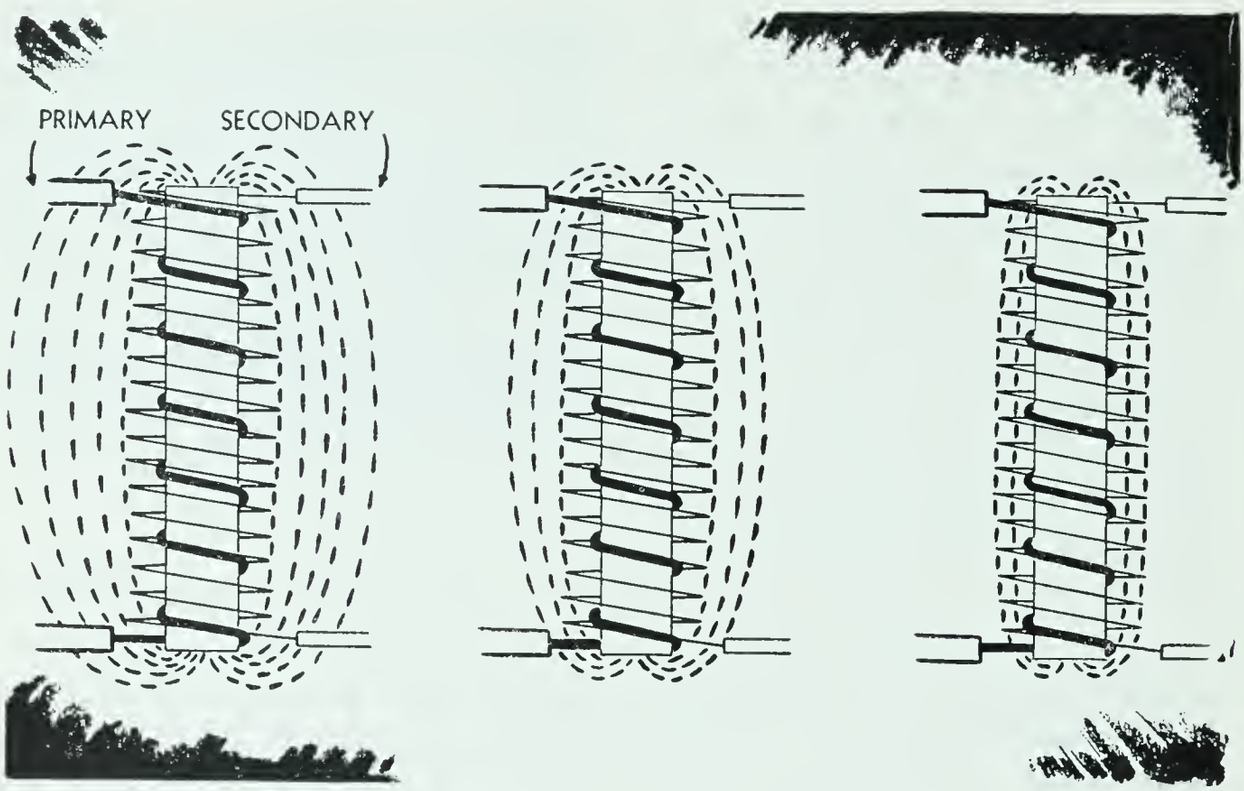
$$\frac{\text{voltage of secondary}}{\text{voltage of primary}} = \frac{\text{number of turns on secondary}}{\text{number of turns on primary}}$$

Since we can vary the number of turns of wire on the primary and secondary, it is possible to vary the voltage of an alternating current within wide limits. If an alternating current having an E.M.F. of 2,300 volts flows through the primary of a transformer which has twenty turns on the primary for each turn on the sec-

ondary, the current induced in the secondary will have an E.M.F. one-twentieth as great—that is, 115 volts. If the connections were reversed so that the current from the generator flowed into the coil of fewer turns, the current induced in the coil having twenty times as many turns would have its E.M.F. multiplied twenty times to 46,000 volts. Transformers are described as "step-down" or "step-up" according to whether the induced alternating current has a lower or higher E.M.F. than the original alternating current in the primary. Oil, pitch, or tar is usually placed around the insulated coils of a transformer to help prevent short circuits.

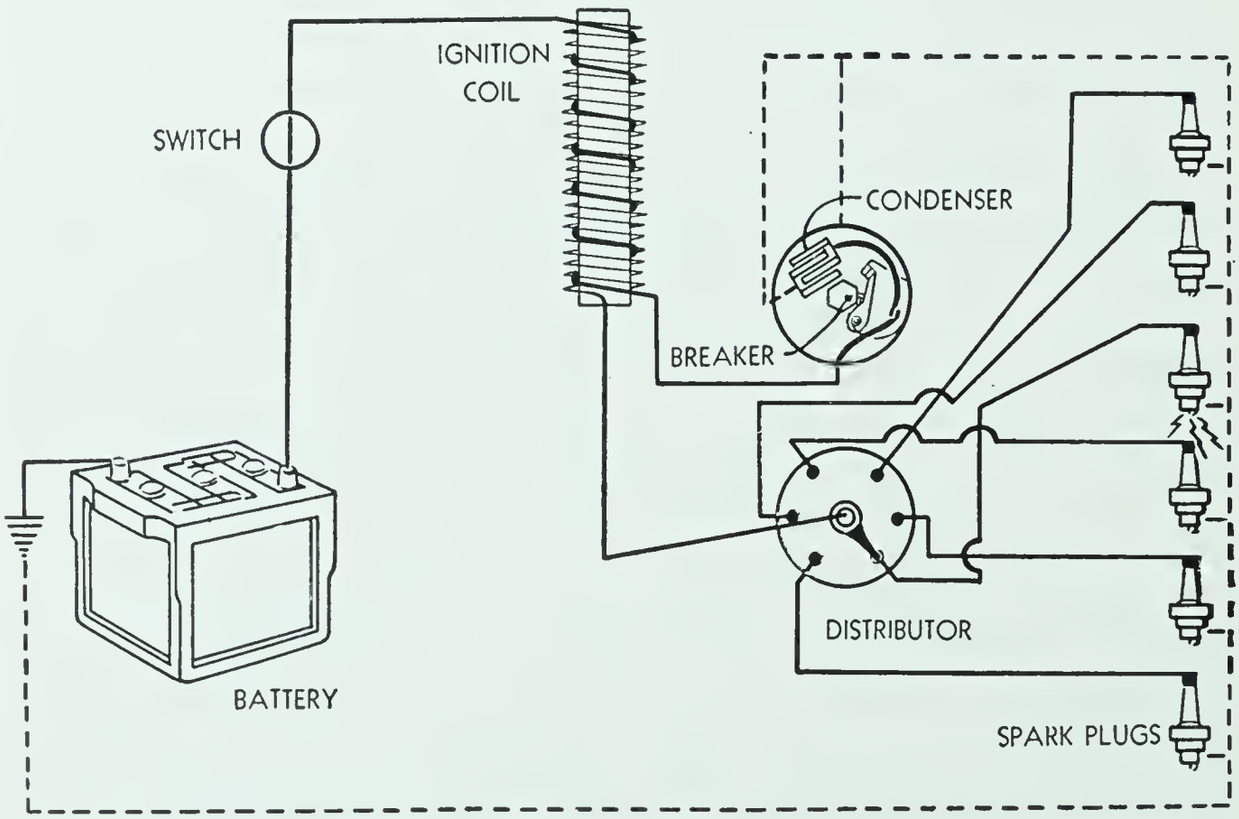
Rarely is alternating current generated by alternators at voltages greater than 13,000 volts; usually the voltage is much lower. As the E.M.F. increases, the difficulty of maintaining adequate insulation between the parts of the generator becomes greater. At Niagara Falls, step-up transformers raise the E.M.F. to 60,000 volts so that electric power can be transmitted economically to distant cities, such as Rochester and Syracuse. Similarly, transformers make practical the transmission to Los Angeles of current under a pressure of 150,000 volts from Big Creek, 240 miles distant. Step-down transformers located in substations reduce the voltage to about 2,300 volts before it enters the cities. Subsequently, smaller transformers again step the voltage down to about 115 volts before it enters the buildings where it is used. Even at this voltage, the current is dangerous if handled carelessly; in fact, tests have shown that when an electrical circuit is completed through a wet contact, *any voltage in excess of 12 is dangerous.*

Although the transformer changes the voltage, there is no gain in energy—it is a voltage changer only. Actually, as in all machines, there is really some loss of energy in the form of heat. As the voltage is raised in a step-up transformer until it has, for example, twenty times as much E.M.F. as before, the amperage decreases until it is slightly *less than one-twentieth* of its former amount. The rate at which electrical energy is delivered (which means electrical power) is measured in watts. Since $W = EI$, simple calculation will show that the power output of a transformer is slightly less than the power input. The efficiency of transformers normally varies from 95 per cent to 98 per cent; this means that they lose as heat only from 2 per cent to 5 per cent of the electrical energy supplied them. Such high efficiency is found in few machines and explains why transformers—and therefore, alternating currents—are so widely used. It is not possible at present to change the voltage of direct currents without large energy losses.



Courtesy General Motors Corporation

The above illustration represents the principle of the automobile induction coil. Why does the number of dotted lines decrease in the drawings to the right?

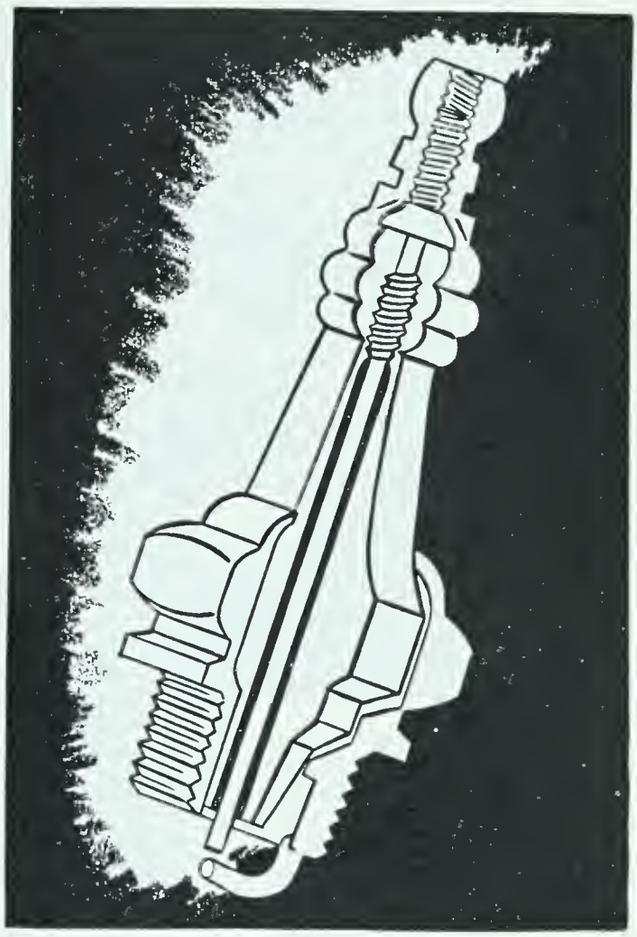


Courtesy General Motors Corporation

This is a diagram of the ignition system of a six-cylinder automobile. What is the purpose of each labeled device in the diagram?

The reduction in amperage by transformers also makes it possible to use smaller wires than would otherwise be necessary for transmission lines. Transformers possess the added advantage of having no moving parts to wear out mechanically.

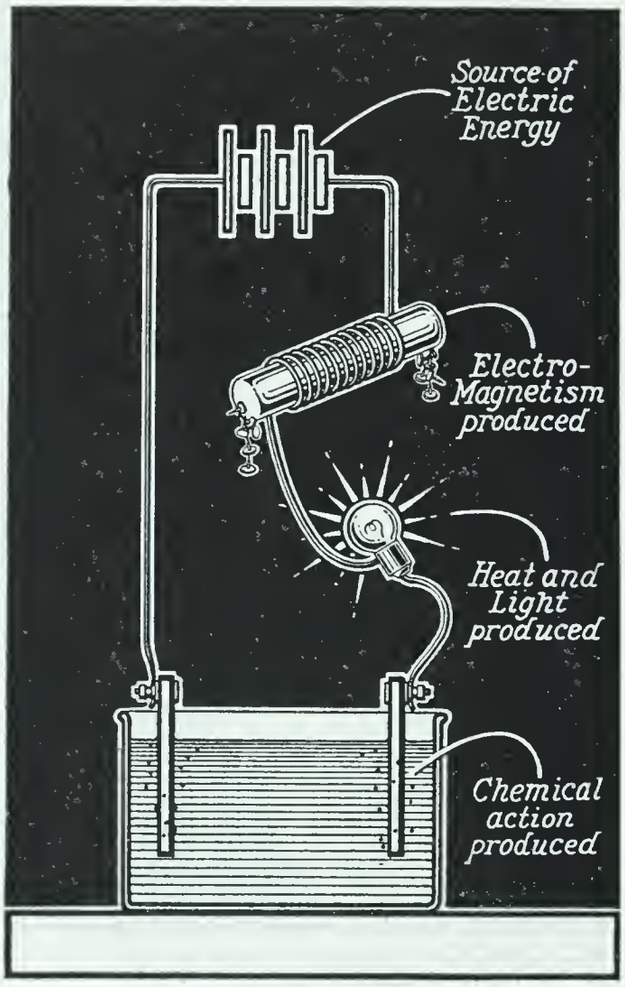
The induction coil is a voltage changer for direct current. It is made up of a primary coil of 150 to 200 turns of fairly large copper wire and a secondary coil of ten thousand to twenty thousand turns of fine copper wire. Both are wound on an iron core. When the primary coil is connected to a battery, a magnetic field builds up surrounding the coil. Since the current flows in one direction only, the magnetic field does not alternate as in the transformer. To bring about this necessary condition, the induction coil has an interrupter in the primary circuit. It works like the vibrator on the electric bell, alternately making and breaking the circuit very rapidly. When the connection between the battery and the primary is broken, the magnetic field quickly collapses. The secondary windings are cut by the collapsing field. As a result of the large number of windings in the secondary, a high voltage is induced. An induction coil is usually equipped with a condenser to prevent sparking at the interrupter and to increase the efficiency of the device.



Courtesy General Motors Corporation

The spark plug builds the fire that makes the wheels go 'round.

Induction coils do an exacting job in igniting the gasoline-and-air mixture in automobile engines. The 6 volts which flow from the battery through the primary windings become 3,500 to 15,000 volts in the secondary windings. This high voltage is necessary to jump the gap in the spark plug and to provide a hot spark in the cylinder. The coil of an eight-cylinder engine must supply more than twelve thousand sparks for each mile the car travels. This is at the rate of 150 a second at 45 miles an hour. In an average year's driving, 150,000,000 fires are built. Each of these fires drives



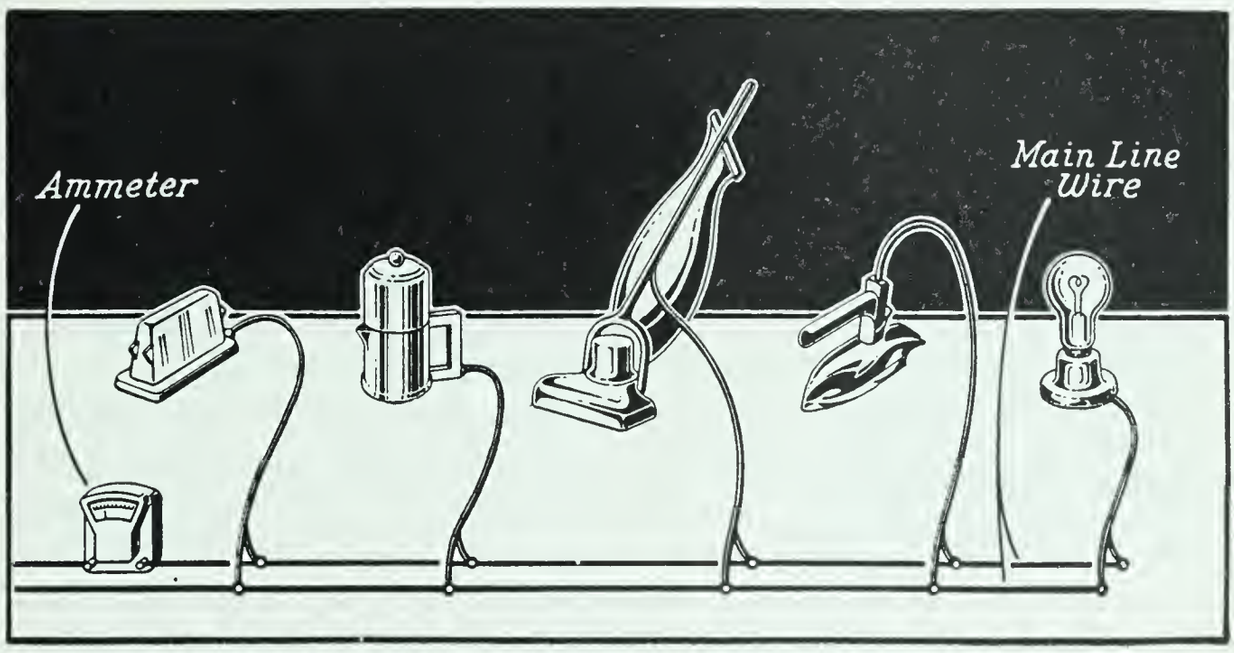
In a series arrangement, all the current must pass through all parts of the circuit.

the car forward about five inches. The ignition system of the car must deliver these sparks at exactly the right time with few or no failures. How this is accomplished is pictured in the diagram on page 166. Spark plugs should be given attention periodically to see that they are in good condition, clean, and with their gaps set properly. If the electric spark does not jump the gap, the fuel is not burned and the engine "misses." This is wasteful and lowers the fuel economy.

In addition to their use for producing sparks in ignition systems, induction coils are employed to operate X-ray tubes, and they find some use in telephone systems. The efficiency of the induction coil is not so great as that of the transformer, and it is not adapted for use with large currents as is the transformer.

• ELECTRICAL CIRCUITS

The appliances which utilize the current after it has been delivered at the proper voltage may be connected in series or in parallel. In a series arrangement, as illustrated on this page, all the current must pass from one device to the next; that is, all the current must pass through all the appliances. A series circuit is illustrated by some Christmas-tree lights in which, if one light burns out, all the lights go out at once because the circuit is no longer complete. It follows from Ohm's law ($I = \frac{E}{R}$) that the amount of current flowing becomes less as the resistance increases. When conductors are connected in series, the total resistance is equal to the sum of the resistances of the separate parts of the circuit. The number of amperes of current flowing in all parts of



These appliances are connected in parallel. Can you explain why?

such a circuit is the same, but this amperage varies as the total resistance is increased or decreased. A complete circuit must be maintained at all times or no current flows. A series of Christmas-tree lights can be used directly on a 110-volt house circuit because the combined resistance prevents the flow of a current large enough to cause them to burn out. One of the same lamps connected directly into a 110-volt circuit would be burned out immediately.

The type of circuit used in our homes illustrates parallel wiring. Series wiring cannot be used in homes for the main circuit because two or three ordinary lamps have a total resistance sufficient to prevent the flow of enough current from a 110-volt line to light them fully. As more lamps are inserted into such a circuit, all lamps become dimmer.

Notice in the above illustration that *all the current does not flow through each device in the parallel system of wiring.* Each appliance is really connected separately across the main line. Parallel circuits are thus divided circuits with more than one path over which current can flow. Some current always flows over each complete path and the fractional part of the total amperage flowing in the main line is greatest in that branch offering the least resistance. The total resistance of a parallel circuit is less than the resistance offered by any one of its parts—even less than that of the branch offering the least resistance. Surprising as this may seem, it is not difficult to understand if you keep in mind that the current has more than one path over which to travel from the point

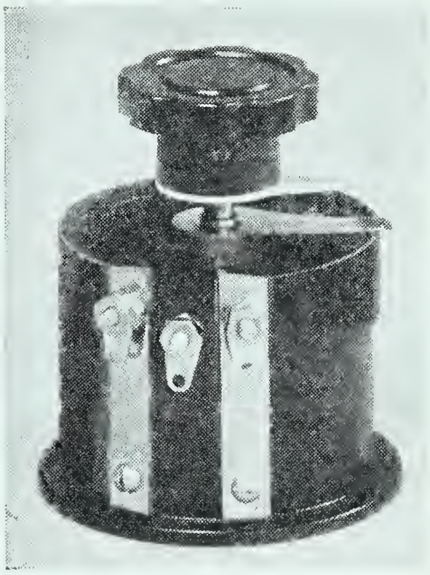
where it enters the parallel circuit to the point where it leaves. Each branch can transport a part of the current with less difficulty than it would have in transporting all of it; conversely, all branches together have less difficulty in transporting the total current than any one would have by itself. Contrasting with series wiring is the fact that the amperage is not the same throughout in parallel circuits, but may be different in each branch, depending upon the amount of resistance offered by each part of the circuit.

Certain advantages of parallel wiring over series wiring can be pointed out from the preceding discussion of the two types of circuits. Switches placed in each branch enable us to use one or more parts of a parallel circuit without wastefully using all of it. Thus in our homes we do not have to turn on all the lights when we wish to have only certain ones lighted. Secondly, since the amperage can vary from branch to branch in parallel wiring, devices requiring different amperages can be used. For example, lights, a vacuum cleaner, and an electric iron, all requiring different amounts of current, can be used in different parts of the home at the same time. The resistance of each individual appliance determines how much current it receives. In a series circuit with its uniform amperage this would not be possible.

Electrical circuits and appliances are protected by fuses and circuit breakers. The total current flowing in the main line of a parallel circuit is equal to the sum of the amperages flowing in all its branches. This raises a question as to how much current can safely flow in the main line; or, in other words, how many appliances can be used safely at one time. There is a limit to the amount of current a wire can transmit without generating excessive heat. Ordinary house wiring can safely carry a current of about 15 amperes. Fuses of this capacity are generally used to protect the main line against overloading. They are placed in the main line near the place where it enters the building. As already has been pointed out, a current greater than 15 amperes develops enough heat to melt the fuse and break the circuit. Each circuit is planned to furnish ample current for the maximum number of appliances that normally will be used, and an extra safety factor is allowed. The carrying capacity of each size of wire has been determined and is always somewhat greater than the size of fuse specified for use with it. A 30-ampere fuse would be no protection if used on a line having a carrying capacity of 20 amperes. In case of an overload or short circuit, the wire would melt before the fuse, with the attendant danger that the building

would be set on fire. The fuse should always have less carrying capacity than the wiring which it is meant to protect. When a fuse "blows" and replacements of the same capacity do likewise, be sure to eliminate the cause rather than insert a replacement of higher capacity.

Larger currents, such as those in powerhouses, have circuit breakers as "safety valves." A circuit breaker is a switch which is automatically opened by an electromagnet. The magnetism is not sufficient to draw up the movable core and thus open the switch until the current reaches a certain minimum value. Electric motors are often protected against overloads by circuit breakers. The sharp report sometimes heard on a streetcar or trolley bus during starting results from the opening of a switch by the circuit breaker. Circuit breakers are being increasingly used instead of fuses in modern home wiring. What advantages can you see in this practice?



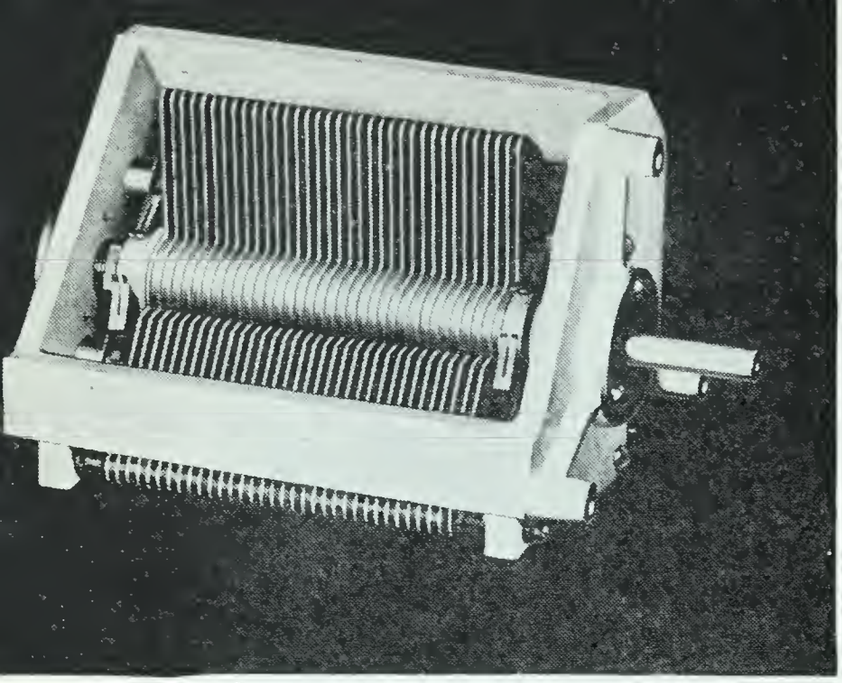
Courtesy General Radio Company

This type of rheostat is used in radio. Do you know how it works?

• CONTROLLING ELECTRICITY

Numerous devices are built into or used with electrical devices to keep the amperage within desired limits. A *rheostat* is simply a coil or combination of coils of high-resistance wire with a movable lever for varying the amount of resistance, and hence the amperage. Nichrome wire, an alloy of nickel and chromium and typical of the wire used in manufacturing such devices, has three advantageous properties: (1) its resistance is nearly seventy-five times that of copper wire of equal size and length; (2) its melting point is high; (3) it does not oxidize easily. Rheostats further illustrate Ohm's law which indicates that the amount of current flowing is inversely proportional to the resistance encountered. Rheostats form part of the starting equipment of streetcars and electric trains. Motors and fans of more than one "speed" are shifted from one speed to another by moving the lever of a rheostat which controls the amount of current flowing. In a similar manner, the lights in theaters are dimmed and radio volume controlled.

Condensers are widely used because (1) they enable us to increase the amount of charge available; (2) in circuits carrying both



Courtesy General Radio Company

This air condenser is used in the radio.

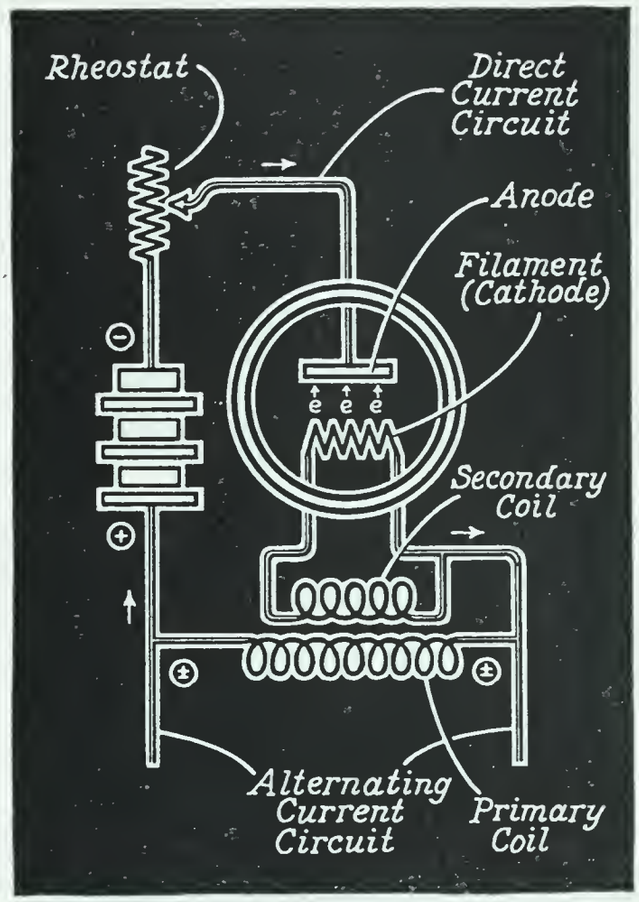
A.C. and D.C. electricity, a condenser will prevent the flow of D.C. but not of A.C. For example, in a telephone system, a condenser may be connected into the circuit so that A.C. bell-ringing current, but not D.C. talking current, passes to the ringer.

One type of condenser consists of sheets of tin foil separated by some insulating material such as mica, glass, or paper. The variable condenser used in radio sets has one set of metal plates fixed to an axis about which can be rotated a set of movable plates. The plates, commonly made of aluminum, are separated by air, which serves as the insulator. Condensers act as storage places for electrons, and the larger the surface of the condenser plates, the greater the number of electrons they can store at the potential used. In the variable condenser, the capacity of the condenser to store electrons can be varied by rotating the movable set of plates so that more or less of its surface lies opposite that of the fixed set of plates. In turning one of the knobs of a radio while tuning, you may be varying the capacity of a condenser; this "tunes" the circuit of the receiving set to that of the broadcasting station. When the capacity of the condenser is increased, the radio set responds to radio waves of greater length. As previously stated, induction coils are also equipped with condensers.

There are several ways of converting A.C. to D.C. While either A.C. or D.C. can be used for running motors and producing heat, as well as for many other purposes, some processes, such as electroplating and the charging of storage batteries, require direct current. Where alternating current is the type sold by the power company, which is usually the case, it is sometimes necessary to convert it into direct current. One way to do this is to use a motor generator. This is simply an alternating-current motor that drives a direct-current generator.

Rotary converters are used to convert A.C. into D.C. for use by streetcars and trolley busses. Alternating current enters a substation from the power lines and is used to rotate an armature as in a motor. From another end of the same armature, direct current flows from a commutator and is supplied to the trolley wire.

Other devices are used where smaller amounts of current need to be converted. The *tungar rectifier* is often used to get direct current for charging storage batteries. The tungar bulb is filled with argon under low pressure and has two electrodes: the anode, made of graphite or tungsten, and the cathode, a spiral of fine tungsten wire. When the spiral is heated by the alternating current, it "boils off" electrons which cause the argon to conduct electricity. Current flows only from the cathode to the anode, however, so that the emerging current flows in one direction only; it is direct but pulsating.

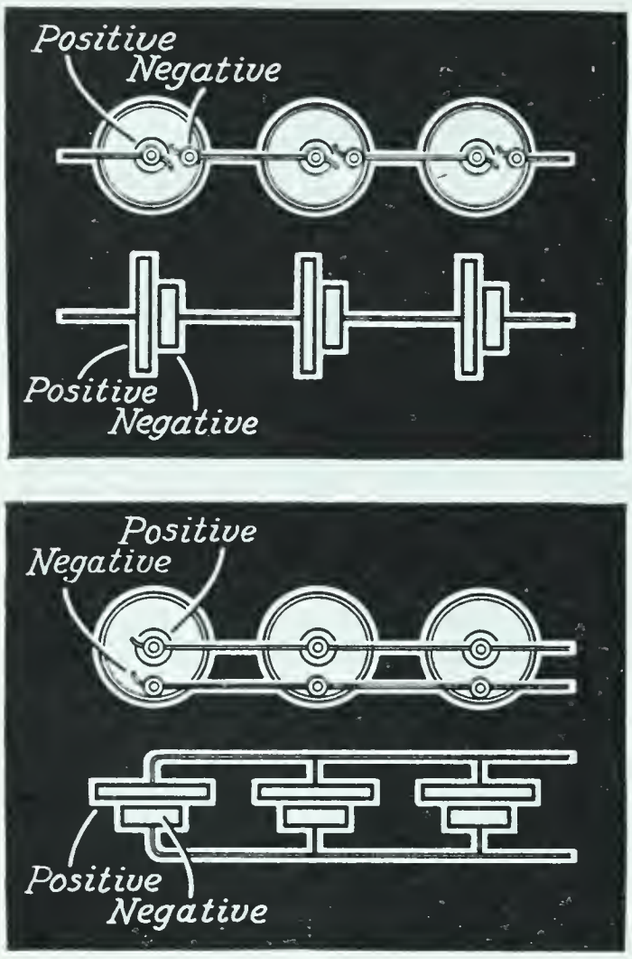


Study the text and explain how the tungar bulb converts A.C. to D.C.

Other types of rectifiers, among them the rectifying tube in A.C. radios, operate on the same principle. They allow electrons to flow in one direction but not in the other. The pulsations in the current supplied by such rectifiers occur because they supply current at the times when A.C. flows in one direction but little or none when it flows in the reverse direction.

There are several ways of using cells and batteries in combination. When two or more chemical cells are used as a source of direct current, the question arises as to whether they should be joined in series or in parallel. Any combination of two or more cells is called a battery. As the next diagrams show, cells are connected in series when an electrode of one cell is joined to that electrode of the second which is opposite in nature, and the other electrode of the second cell to the opposite kind of the third cell, and so on. The free electrodes of the first and last cells, which are always opposite in kind, are connected to the external circuit through which the current is to flow.

In a parallel arrangement of cells, the positive electrodes of the cells are all joined together as are all the negative electrodes. The voltage of a series combination of cells is equal to the sum of the



Which is the series and which is the parallel arrangement of cells?

voltages of the single cells. In a parallel arrangement, the E.M.F. of the combination is the same as that of a single cell. To get the maximum amperage from a group of cells, they must usually be connected in series. Only when the resistance of the external circuit is small in comparison with that of the internal circuit of the cells will the parallel arrangement deliver more amperes than the series combination. Rarely is the external resistance less than the internal resistance.

Several cells are sometimes connected in parallel and used where one cell could do the task, as, for example, in ringing a doorbell. It is found that dry cells last longer when used this way than when the same number of cells are used singly, one after the other, until all have been worn out.

• SAFETY IN THE USE OF ELECTRICITY

Electrical appliances which operate on the so-called "low voltage" used in house circuits always present the possibility of electric shock. This is a hazard usually looked upon by householders as trifling and unimportant. As a matter of fact, it demands extreme caution. Although ordinary house current does not usually shock severely, it is dangerous under some conditions, and even low voltages—not much over 12 volts—have been known to produce fatal results. The normally high resistance of the body to the flow of electricity becomes quite low if the body is well "grounded," as when immersed in salty or soapy water, when moist from sweat, or when the skin is cut or broken. Then, large and deadly currents may be forced through the body. This explains why so many persons coming in contact with the house circuit while bathing have been killed. Some deaths have resulted

from electric hair dryers, ultraviolet lamps, and radio sets falling into bathtubs; others have resulted from the bather's touching an electrical fixture. Never touch an electrical switch while bathing! If a metal pull chain is used to turn the bathroom lights on and off, see that it has one or more insulating links at some point separating the metal ones.

Electric shock affects the nerves. When nerves stop sending impulses to the muscles, very few body functions can continue and the victim dies, unless nerve action resumes in a very short time. A person who has been severely shocked by lightning or electric current loses consciousness and may stop breathing because the passage of current through the brain affects the breathing center at the base of the brain. Sometimes the victim's body becomes rigid. Begin artificial respiration at once and continue for three or four hours if necessary, even if there is no sign of revival. As in all cases of severe injury, send someone immediately to call a physician.

Great care must be exercised in freeing a person who is in contact with a live wire. It is very simple for the would-be rescuer to become the second victim. If the line switch can be quickly located, turn off the current; if not, phone the power company to shut it off. In attempting to free the victim while the current is still on, stand on some insulating material like dry wood. Use only insulators, such as dry sticks, rope, or cloth, while attempting to remove the victim from the wire or the wire from the victim.

Generally speaking, electrical appliances are no safer to use than are the cords which supply them with current. When electrical instruments become defective and worn, they are usually sent to an electrical shop for repairs; but many people run severe risk of fire, shock, or other inconvenience by trying to squeeze the last penny's worth from an old appliance cord, or by being neglectful of the need for repairs. Ordinarily, appliance cords undergo more wear and tear than the appliances themselves. Cords for heating appliances, especially electric irons, receive very hard usage and therefore need special attention. Minor repairs, if made in time, will usually make a dangerous cord as good as new. It is easy and inexpensive to repair or replace broken caps, connectors, and frayed or broken cords.

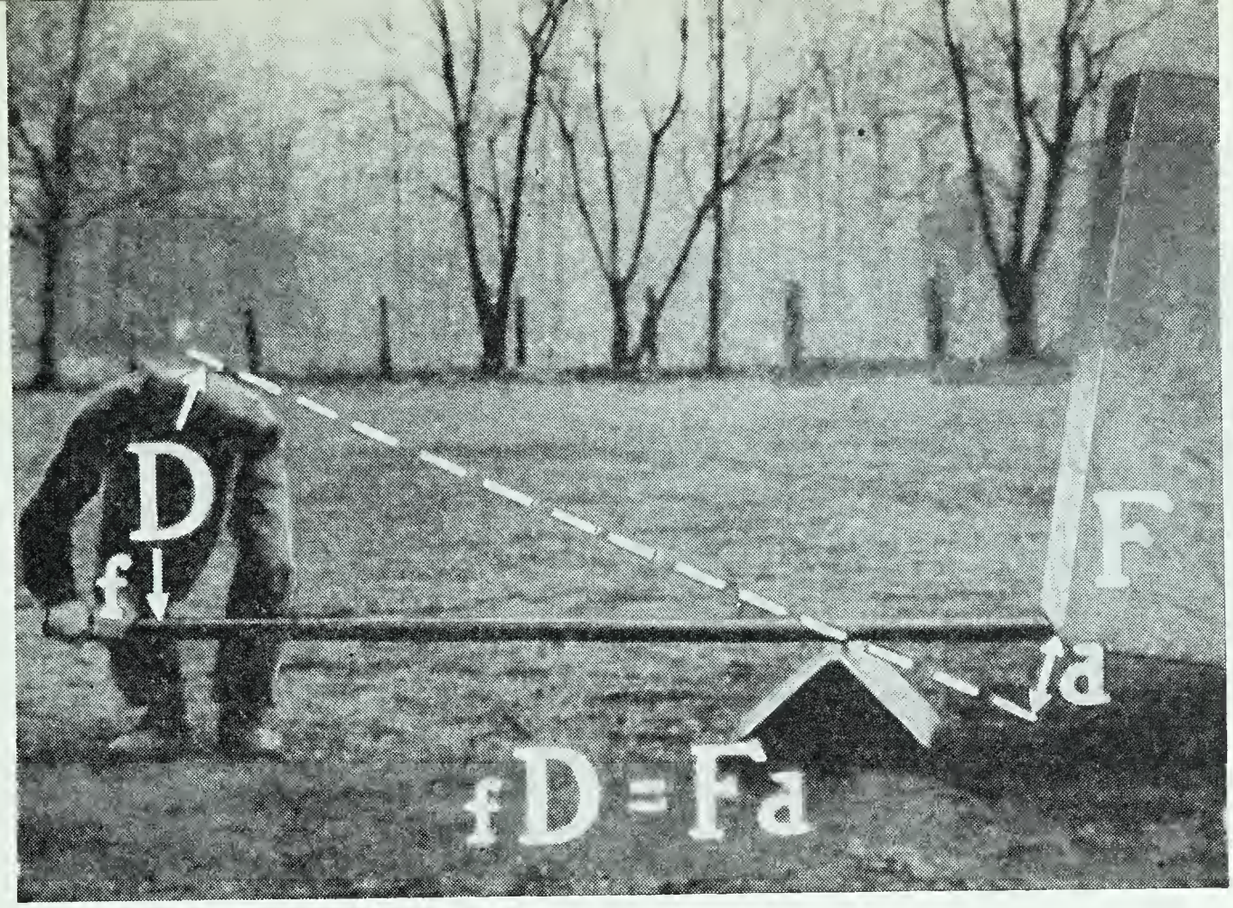
When purchasing new wire, be sure it is of the proper size to carry the amount of current the appliance will draw. Cords which have wires too small heat readily and destroy the insulation rapidly. Asbestos-covered cord is preferable for heating appliances; for use in wet places, rubber-covered cord is desirable. All cord or

wire should carry the band of approval of the Underwriters' Laboratories. Reputable dealers can usually supply properly insulated wire of the correct size if they know its intended use.

All wiring of buildings should be done by competent electricians. They are not competent unless they are familiar with the requirements of the National Electrical Code, established by the National Board of Fire Underwriters. Most cities have electrical codes and enforce inspection of the wiring in new buildings, but many smaller towns and rural districts do not. Power companies, however, usually inspect new wiring before supplying service, and fire-insurance companies often provide inspection before issuing insurance coverage. Improperly installed wiring and equipment are hazardous to the lives of persons using them and may render null and void any fire insurance carried on the property. It is wise, therefore, to avoid the services of amateur electricians and handymen, who, through ignorance and incompetence, do not attend to the details necessary for the safe use of electricity.

Exercises for Problem Study and Review

1. Show that the transformer makes use of both the principle discovered by Oersted and the principle discovered by Faraday.
2. Why won't a transformer work with direct current?
3. Why should the primary of an induction coil be made of heavy copper wire and the secondary of fine wire?
4. If a heavy wire is touched to the two terminals of a storage battery, there may be a shower of sparks, but no shock is felt. If you touch a spark plug when the engine is running, you receive a severe jolt. How do you explain this?
5. Explain how the use of a rheostat is an application of Ohm's law. What electrical devices in or around your home contain rheostats?
6. What is the E.M.F. of three ordinary dry cells connected in series? In parallel? Which way would you connect them for use in ringing a doorbell? Why?
7. Radio "B" batteries are really dry batteries constructed of the same materials as the ordinary dry cell. How can they give an E.M.F. of 22½, of 45, of 90 volts?
8. In short, clear sentences, summarize the precautions to be observed around the home in the use of electrical appliances.
9. Why is it desirable, or even necessary, to step down the voltage of an electric current before leading it into houses?
10. Explain why power companies prefer to transmit at high voltage and low amperage, rather than at low voltage and high amperage. How is it possible to do this?



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By means of a lever, a small force acting through a large distance can overcome a large force acting through a correspondingly small distance.

11. An electric toaster of 20 ohms, an electric lamp of 150 ohms, and an electric soldering iron of 10 ohms are connected in series to a 120-volt line. What is the current through each appliance? What is the total current?

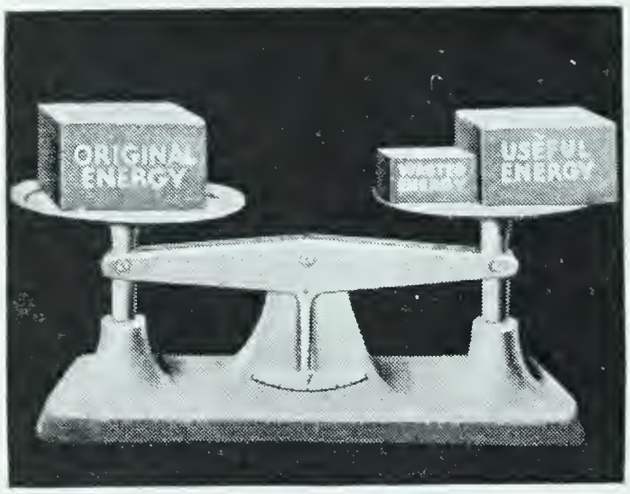
12. The three above appliances are connected in parallel to a 120-volt line. What is the current through each one? What is the total current in the main line? What would happen if the line were protected by 15-ampere fuses?

Problem 5: How does man use power in the accomplishment of work?

• BASIC IDEAS REGARDING MACHINES

We use machines to transform or to transfer energy in such a way as to gain some mechanical advantage. The advantage gained by using a machine may be that the force exerted upon the machine is multiplied so that it can overcome a larger force or the machine may speed up the rate at which we can perform a task. Sometimes a machine is used simply because it changes the direction in which a force is applied.

To say that a machine multiplies a force, increases speed, or changes the direction in which a force is applied may make it



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The above illustration represents the law of machines.

appear that machines offer advantages only. However, every time a force is multiplied, as, for example, when an automobile is lifted with a jackscrew, the resistance never moves as far as the force which is exerted upon the machine. On the other hand, whenever a machine is used to increase speed, it does so only with the expenditure of greater force than would otherwise be needed. The bicycle is an example of such a machine which sacrifices effort for speed. All machines possess the disadvantage that some force must be used up in overcoming the friction of the machine. This is the only disadvantage when a single fixed pulley is used to help raise a weight from a lower to a higher level. We use it because it enables us to pull downward instead of upward.

The mechanical advantage of a machine is a number which tells how many times the machine multiplies the force exerted upon it. A machine in which an applied force of two pounds is enabled to overcome a resistance of six pounds, has a numerical mechanical advantage of three. Thus,

$$\text{M.A. (mechanical advantage)} = \frac{\text{R (resistance force overcome)}}{\text{E (effort force applied)}}$$

The theoretical, or "ideal," mechanical advantage can be computed by dividing the distance through which the effort moves (D_E) by the distance through which the resistance moves (D_R). This method neglects the fact that some work is done to overcome the friction of the machine. Therefore, ideal M.A. is always greater than actual M.A. As losses due to friction are decreased, as, for example, by lubricants, the actual M.A. more nearly approaches the ideal M.A., and the efficiency of the machine increases.

To find out how much work a machine does we must consider not only how heavy an object is moved but also how far it is moved. Six foot-pounds of work are done when an object weighing three pounds is lifted a distance of two feet. In the English system, the *foot-pound* is the unit of work. The number of foot-pounds

of work done is found by multiplying the number of feet of space through which an object is moved by the number of pounds of resistance overcome. This is in accordance with the scientific formula for work:

$$\text{work} = \text{force} \times \text{distance}$$

The work *done by* a machine is called the *output;* the work *done upon* it is called the *input.* Input is always greater than output because some of the input is used to overcome the friction of the machine and is wasted in the form of heat. If there were no friction, output and input would be numerically equal and perpetual-motion machines would be possible. The *law of machines* may be stated as follows:

(Output)
Useful Work Done + Losses Due to Friction = Input

Since useful work is calculated by multiplying resistance and resistance distance ($R \times D_R$), and input by multiplying effort and effort distance ($E \times D_E$), we may say that, neglecting losses caused by friction,

$$R \times D_R = E \times D_E$$

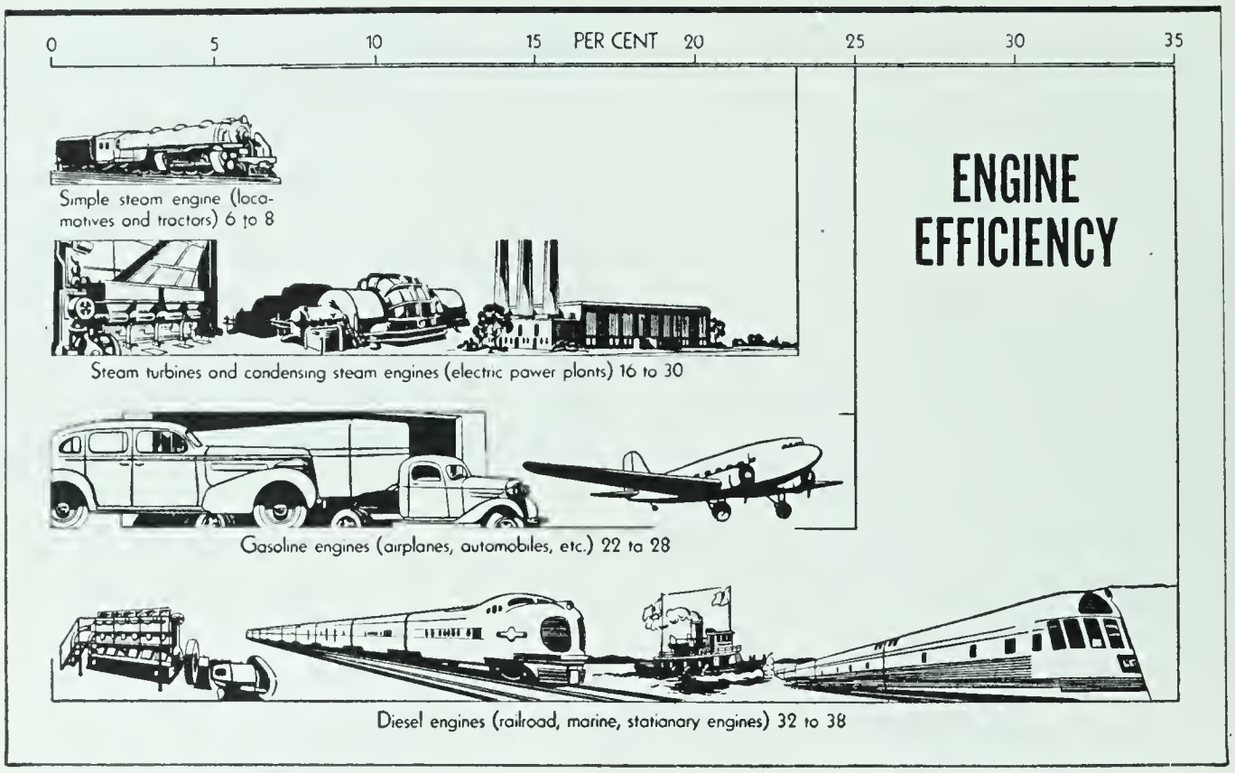
Whether or not a certain machine is selected to perform a given task depends in part upon how much of the input it can change into useful work or output; in other words, its efficiency must be taken into consideration. A machine which does 40 foot-pounds of work when 80 foot-pounds of work are done upon it is said to be 50 per cent efficient. The efficiency of any machine can be determined by dividing the output by the input:

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

Another method of calculating efficiency is to divide the actual mechanical advantage by the ideal mechanical advantage:

$$\text{efficiency} = \frac{\text{actual M.A.}}{\text{ideal M.A.}}$$

Since machines will usually convert more of the input into output at certain speeds than at others, the efficiency of the same



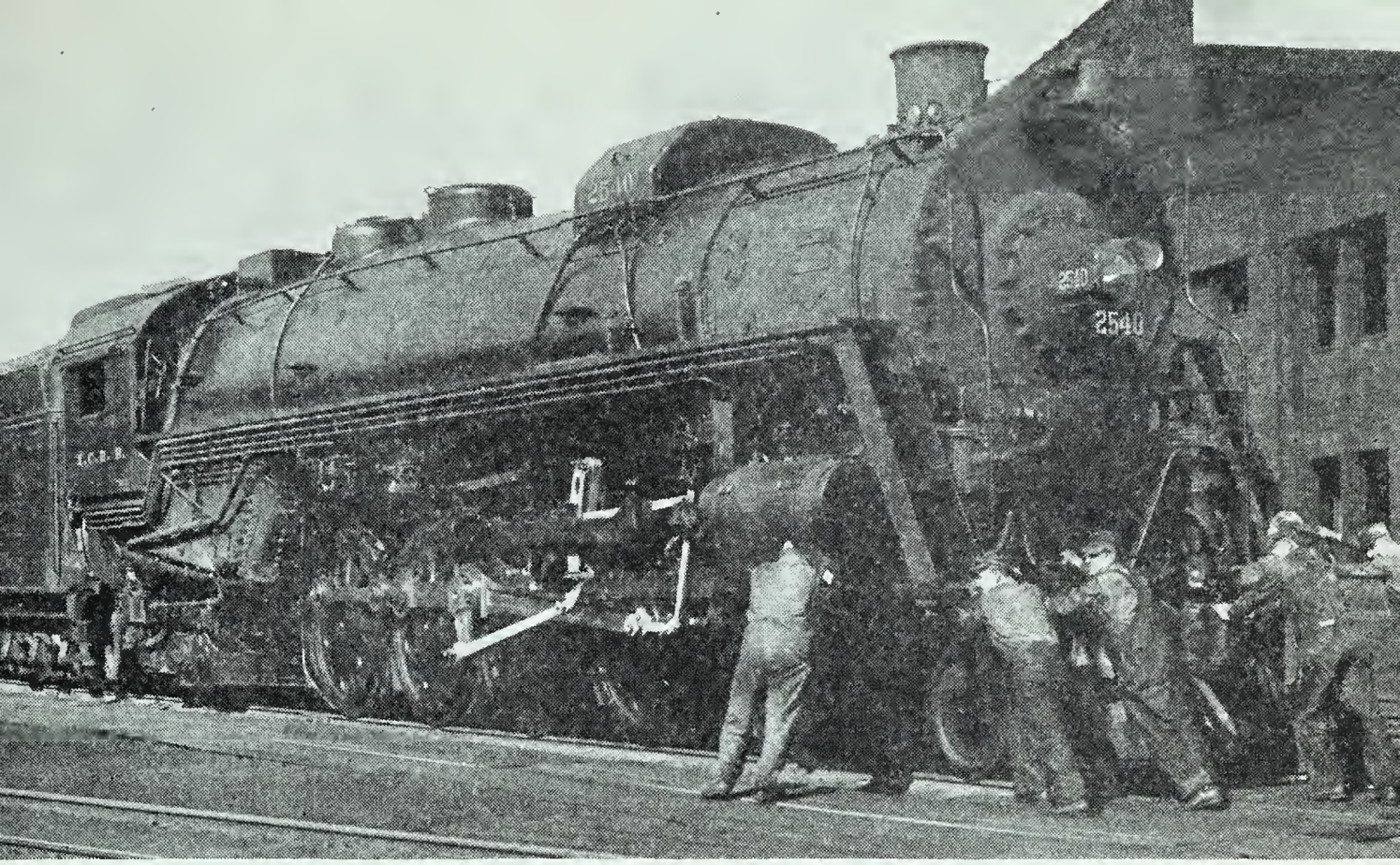
Courtesy General Motors Corporation

Machines vary in efficiency.

machine does not ordinarily remain constant for all conditions under which it is operated.

When an object is too heavy to lift, you are sometimes able to slide it to the place where you wish it to be. In this way it is often possible to move a 100-pound object by exerting a force of 25 pounds or less. The force which must be used to overcome friction divided by the weight of the object gives a result which is called the *coefficient of friction.* If a force of 25 pounds is enough to push a 100-pound object over a given surface, the coefficient of friction is 25/100, or 0.25. The nature of the rubbing surfaces determines the coefficient of friction—not the weight of the object, the surface area in contact, or any other factor. If the surfaces which rub against each other are highly polished or if oil, grease, graphite, soap, or other lubricant is used between them, the force needed—and hence the coefficient of friction—may be greatly reduced. Certain substances such as Babbitt metal, an alloy which is placed around the axles of heavy machinery, give comparatively small coefficients of friction when objects move over them.

If the rubbing surfaces are hard, friction can usually be reduced still further by arranging for rolling instead of sliding. Thus if an object is so heavy that you can neither lift it nor slide it, you can usually use a lever to pry it up far enough to place pieces of pipe or other rollers under it. The rollers may greatly reduce the force



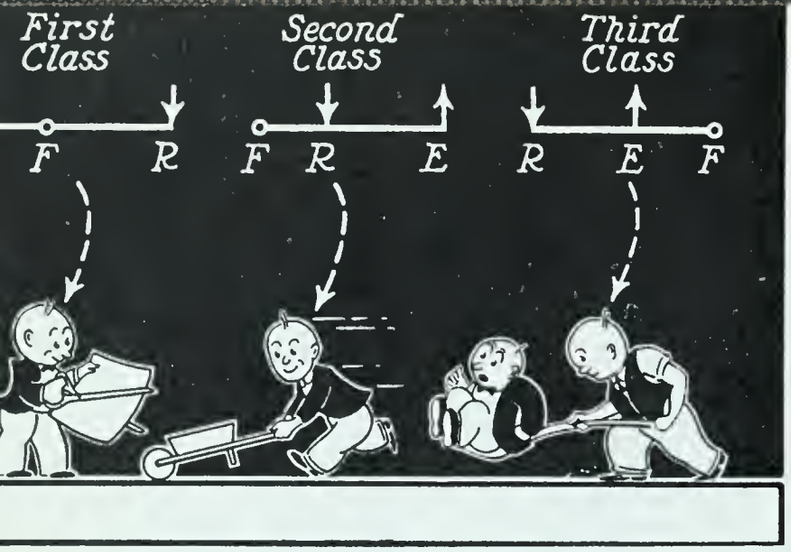
Courtesy Illinois Central System

Believe it or not—six men were able to push this huge locomotive after it had been overhauled and equipped with new bearings. How would this affect the over-all efficiency of the engine?

required to move the object. The nature of the surface over which the rollers move is also very important. You would not try this procedure in soft earth or snow where rolling friction is likely to be greater than sliding friction. However, we commonly move objects over rather hard surfaces and rollers then are very advantageous. This explains why ball bearings or roller bearings are used around the moving parts of machines when it is necessary to hold friction to a minimum.

• SIMPLE AND COMPOUND MACHINES

The six simple machines are the lever, pulley, wheel and axle, inclined plane, wedge, and screw. *The lever.* A lever is a rigid bar which is moved about a fixed support called the pivot point or fulcrum. The use of a crowbar to pry loose a heavy stone or of oars to row a boat illustrates common applications of this simple machine. Note in the diagram on the next page that levers are divided into three classes according to the relative positions of the fulcrum, effort, and resistance. The effort arm of a lever is measured from the fulcrum to the point where the effort is applied, the resistance arm from the fulcrum to the point where the resistance is applied. If we selected three levers of the same length and decided to use one as a first-, one as a second-, and one as a third-class lever,



Cite some other examples of each class of lever.

the second-class lever could be arranged to give a greater mechanical advantage than either of the other two. This is true because the second-class lever would have a longer effort arm than either of the other two and, for the lever,

$$\text{ideal M.A.} = \frac{\text{effort arm}}{\text{resistance arm}}$$

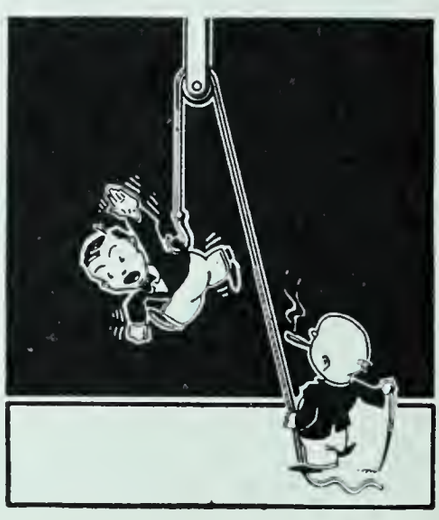
Third-class levers give the advantage of speed at the expense of effort.

The pulley. A wheel, usually grooved, turning about a fixed axis in a frame or block is called a pulley. A set of blocks having one or more pulleys each, together with the rope connecting the pulleys, is called a block and tackle. Pulleys may be used singly or in various combinations.

A single fixed pulley has an ideal mechanical advantage of 1; that is, a force of 1 pound must be exerted to lift a weight of 1 pound. Its actual mechanical advantage is less than 1 because of ever-present friction, and a force somewhat greater than 1 pound would be required to lift the 1-pound weight. There is an important advantage, however, in the fact that the direction in which the force is exerted can be changed to suit one's convenience by proper placement of the fixed pulley.

A single movable pulley has an ideal mechanical advantage of 2. A force of 1 pound would move a weight of 2 pounds if there were no friction. The disadvantage is that the weight moves only half as far as the applied force.

What is the mechanical advantage of the single fixed pulley?



Various combinations of fixed and movable pulleys are used and some of them are shown in the accompanying diagram. Each division of the rope passing around the various pulleys is called a strand. *In all combinations of pulleys, the ideal mechanical advantage equals the number of strands supporting the movable block.*

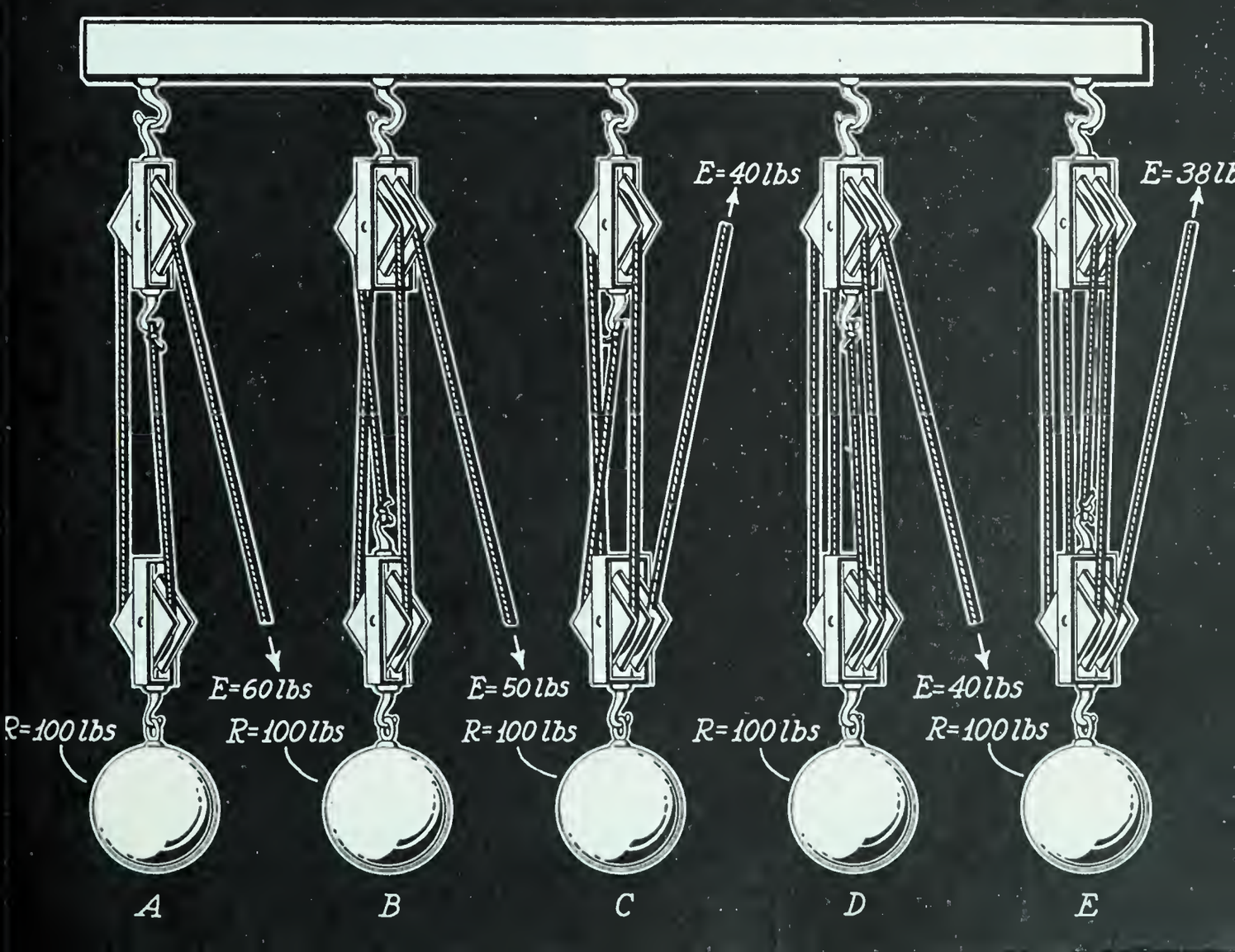
The wheel and axle. The windlass for drawing water from a well is a good example of this simple machine. The effort is exerted at the circumference of the wheel described by the handle; the resistance acts at the circumference of the axle upon which the rope winds. Other examples of this type of machine are seen in the steering wheels of motor boats, in hoisting derricks, in ice cream freezers, clothes wringers, and doorknobs. As in all machines the ideal mechanical advantage equals the effort distance divided by the resistance distance. In the wheel and axle then,

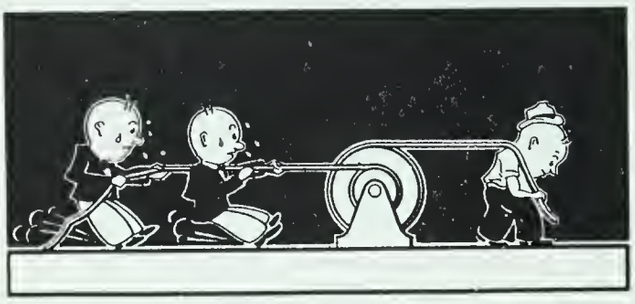
$$\text{ideal M.A.} = \frac{\text{circumference of wheel}}{\text{circumference of axle}}$$

Obviously, the same M.A. could also be obtained by dividing the diameter of the wheel by the diameter of the axle, or the radius of the wheel by the radius of the axle.

The inclined plane. The person who rolls or slides a heavy object upwards upon a plank reaching from the ground to a truck body makes use of the inclined plane. Since he uses the inclined

A combination of fixed and movable pulleys is known as a block and tackle.





A small force acting on the wheel can overcome a larger force acting on the axle.

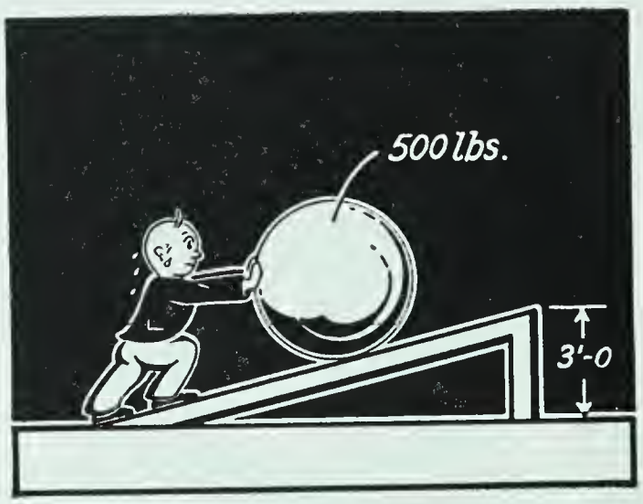
plane because the object is too heavy to lift directly, it is evident that this machine is used to multiply the force exerted. The resistance distance is the height of the plane and the effort force acts through the length of the plane, provided it is applied parallel to the plane. In such cases, therefore,

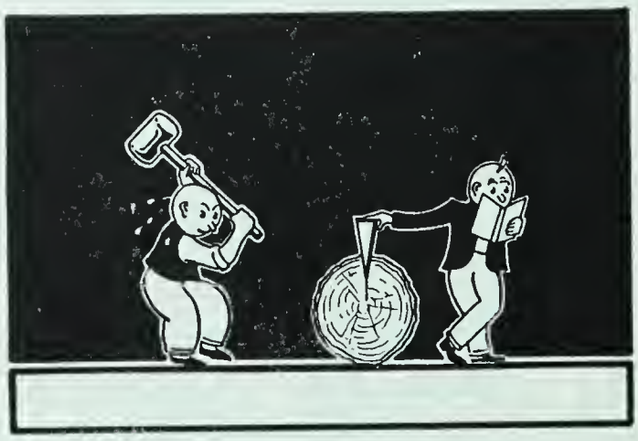
$$\text{ideal M.A.} = \frac{\text{length of plane}}{\text{height of plane}}$$

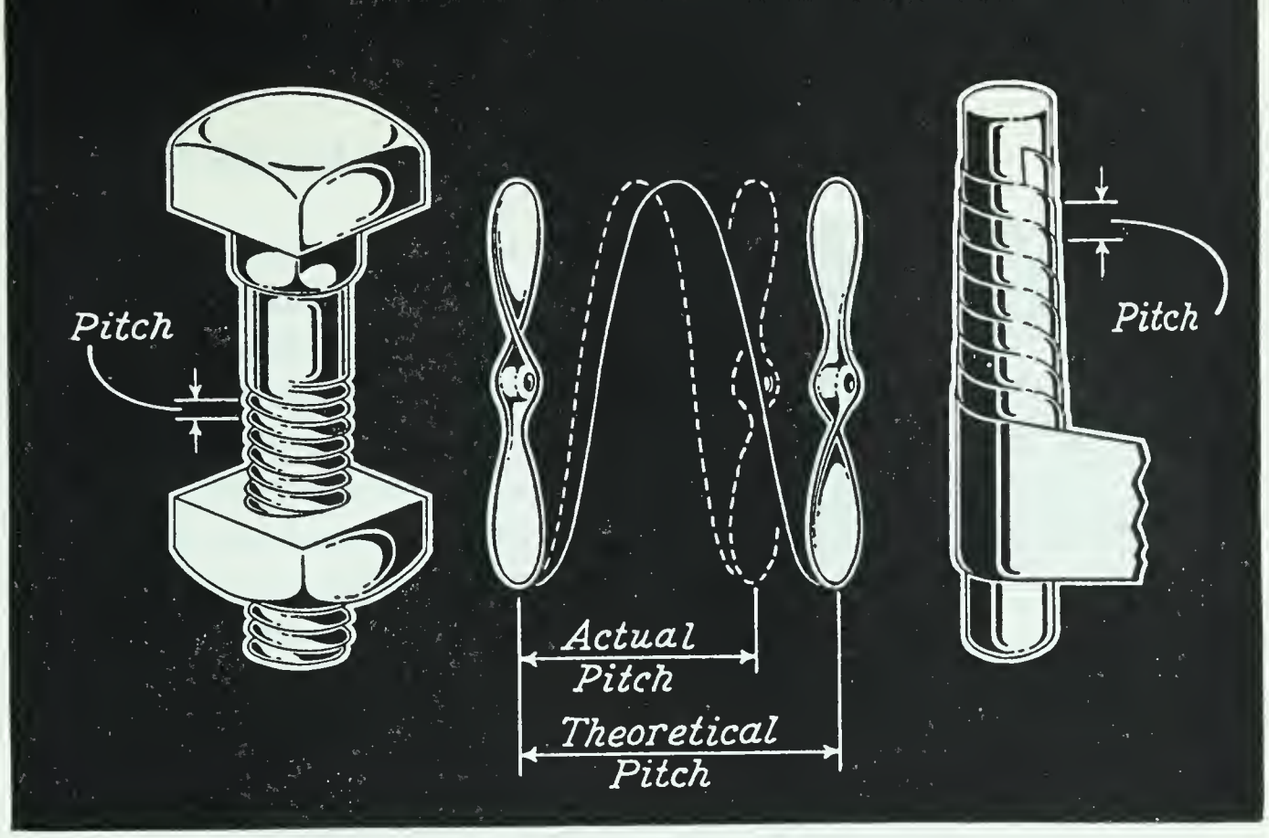
Ramps from lower to higher levels, such as are sometimes constructed for driving automobiles to the upper floors of garages, illustrate another use of this simple machine.

The wedge. The wedge is really a double inclined plane. An axe, nail, pin, or chisel when pushed or driven through some resisting material acts as a wedge. The mechanical advantage depends upon the ratio of the length of the wedge to its thickness. Thus a long, thin wedge gives a greater mechanical advantage than a short, thick one.

The screw. Screws are also modifications of the inclined plane. Common examples of this simple machine are seen in the jackscrew, turnbuckle, micrometer caliper, mechanic's vise, water faucet, nut and bolt, wood screw, and airplane propeller. In this machine, a force acting through the circumference of a circle overcomes a larger resisting force which acts through a shorter distance equal to the space between two consecutive threads of the screw. The distance between two consecutive threads of a screw is called its *pitch.* As in other machines, the actual mechanical





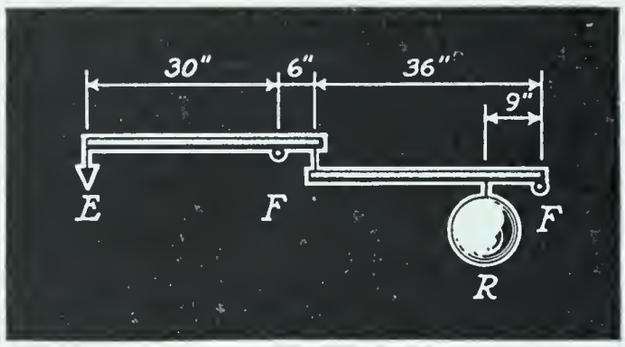


The screw is a cylindrical inclined plane.

advantage is obtained by applying the formula $\frac{R}{E}$; the ideal mechanical advantage is obtained by means of the formula $\frac{2\pi r}{S}$, where r is the radius of the circle through which the force acts and S is the pitch of the screw.

A compound machine is usually a combination of simple machines acting together. When one simple machine acts upon another in such a way that they cooperate in performing a task, the mechanical advantage of the system becomes, not the sum of the separate mechanical advantages of the simple machines, but their *product.* In the combination of levers shown in the next diagram, a lever with an ideal M.A. of 5 and one with an ideal M.A. of 4 form a lever system with an ideal M.A. of 20. This can be verified, as in a simple machine, by dividing the effort distance by the resistance distance to get the ideal mechanical advantage of the system or by dividing the resistance by the effort to get the actual mechanical advantage.

A worm gear is often used to increase power and decrease speed. Trucks which employ this combination of screw, toothed wheel, and lever are said to have a "worm drive." Each revolution of the screw turns the wheel through a distance equal to the pitch of the screw. If the pitch of the screw were one inch and the circumference of the wheel fifty inches, the force exerted by the drive shaft on the screw would be multiplied fifty times, but the wheel would make only one-fiftieth of a revolution for each revolution of the driveshaft. Since electric motors run best at high speeds,



Two levers combine to form a compound machine.

worm gears are sometimes coupled to them to reduce speed and multiply force.

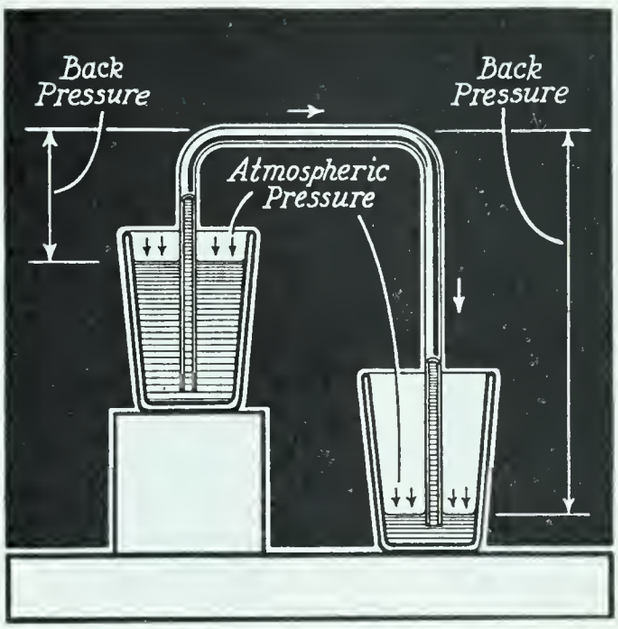
Analyze some complex machines, such as the differential pulley, sewing machine, and typewriter, and see if you can recognize the simple machines which have been combined in them. The differential pulley consists of a wheel and axle and a pulley. In sewing machines, the lever, inclined plane, and wheel and axle can be found. Typewriters employ chiefly the three classes of levers.

• PNEUMATIC AND HYDRAULIC MACHINES

Pneumatic appliances, like other machines, illustrate the principle that motion results when forces become unbalanced. In these devices the forces are exerted by gases. Advantage is often taken of the fact that the atmosphere itself exerts a normal pressure at sea level of about 15 pounds on each square inch of surface. If a region of less pressure can be properly maintained, the force of the atmosphere can be used in accomplishing work.

The siphon is a device which thus uses the pressure of the atmosphere to transfer liquids over an elevation from a higher to a lower level. As shown in the diagram, the downward arrows indicate that the atmosphere is exerting its pressure on the surface of the liquid in each container. There is a backward pressure on either side of the siphon due to the weight of the liquid in each arm of the siphon. Since the backward pressure is always greater on the side with the longer arm, the forces become unbalanced, and atmospheric pressure pushes liquid from the higher container to the lower one. The rate of flow tends to increase as the difference between the vertical lengths of the arms is increased.

Another appliance in which the pressure of the atmosphere is harnessed is the lift pump. It is often used to raise water from wells. In the diagram of the lift pump, you see that it has a cylinder in which a piston is moved up and down by means of a pump handle. There is a valve in the piston and another over the opening of the pipe which leads from the cylinder downward to the water. When the piston moves upward, the piston valve, V_2, remains closed and the air is lifted out of the cylinder, leaving a

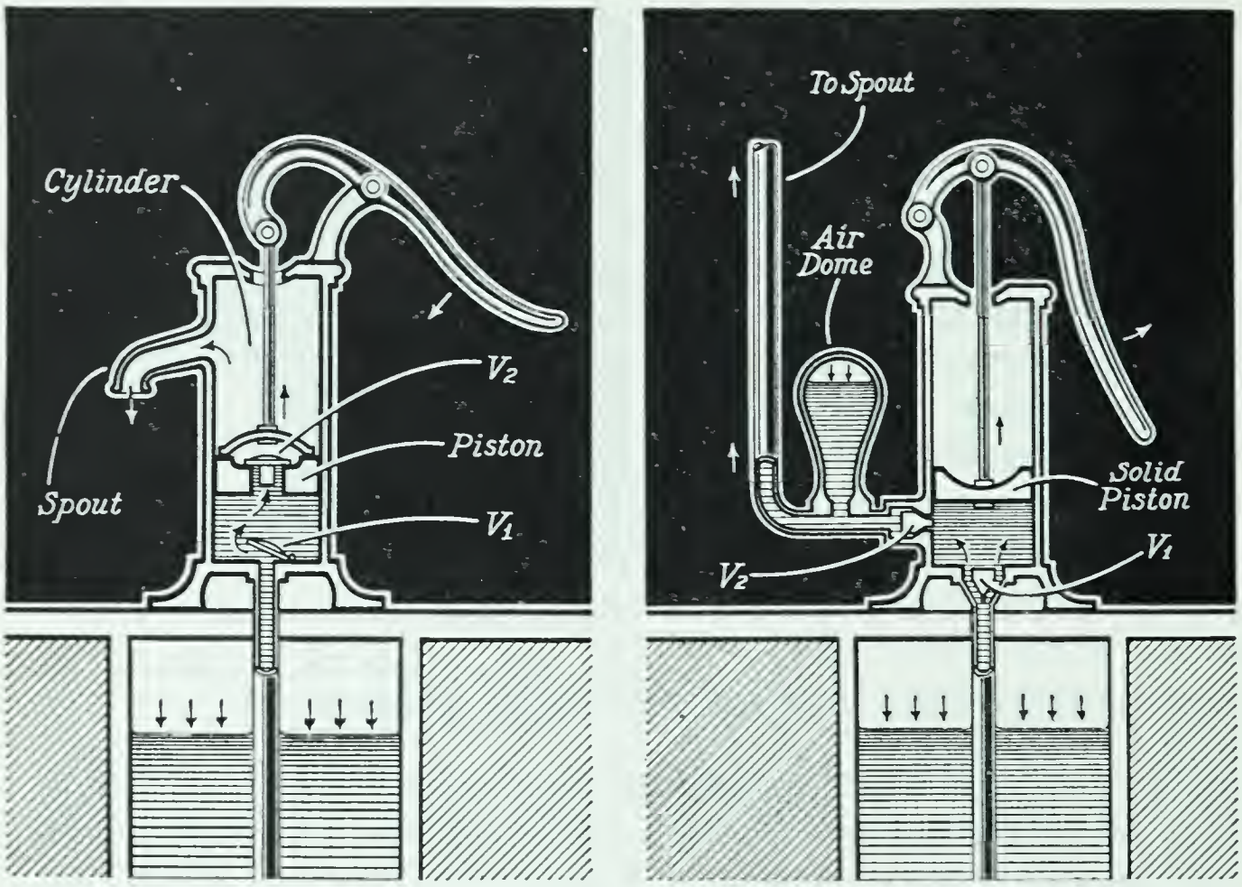


The siphon operates because of unbalanced pressures.

partial vacuum below the piston. Atmospheric pressure on the water in the well pushes water up the pipe. The water forces open valve V_1 and flows into the cylinder. As the piston moves downward, valve V_1 is forced shut, thereby preventing the water from flowing back into the well. The downward stroke also opens valve V_2, and water flows above the piston. The next upward stroke of the piston lifts water to the spout where it escapes. In the meantime, valve V_1 has been open, and the atmosphere has been refilling the cylinder with water for delivery at the spout upon the next upstroke of the piston.

There is a limit, however, to the height to which the atmosphere can force a column of water. When the height of a vertical column of water reaches 34 feet, the back pressure due to its weight becomes equal to atmospheric pressure. Since it is impossible to maintain a perfect vacuum above the water column, it is found in practice that the lift pump does not work satisfactorily when the cylinder is more than about 28 feet above the level of the water in the well. The siphon and other devices depending upon atmospheric pressure have the same restriction as to the vertical height through which the liquid can be raised. Liquids weighing more per cubic foot than water cannot be raised as high as water.

Some pneumatic appliances operate by means of pressures increased beyond that of the atmosphere. From your experience with the inflation of bicycle or automobile tires, you know that air can be crowded into one-third, or even one-fifth or less, of its normal volume. The tendency of the air to expand again is demonstrated by the way this compressed air rushes out of the tire when the valve is opened or the tire is punctured. The firmness of the tire when inflated results from the pressure due to the molecular bombardment of the compressed gas. The force which compressed gas exerts when allowed to expand is used as the driving force in such pneumatic devices as the force pump, air



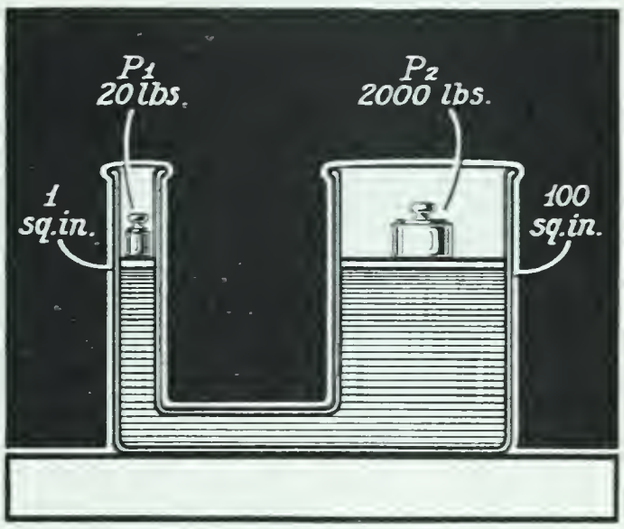
What are the differences and the similarities in the lift pump and the force pump?

brake, diving bell, pneumatic hammer, and pneumatic riveter, which operate on compressed air.

Force pumps are substituted for lift pumps when water must be raised to a higher level than the location of the pump itself. The diagram shows that the force pump differs from the lift pump in two respects: (1) in the location of valve V_2; (2) in the addition of an air dome. Except for the action of the air dome, the operation of the two pumps is very similar. When water is forced rapidly into the air chamber by the downward stroke of the solid piston, the air in the dome is compressed. The expansion of this compressed air when the piston is moving upward discharges water during the period when no water would be delivered if there were no air dome. Thus the flow of water from a force pump is continuous, while in a lift pump it is not.

Hydraulic machines make use of liquids to transmit pressure. There is a striking difference between gases and liquids in the extent to which they can be compressed when pressure is applied. If a stopper which has been inserted into the neck of a bottle completely filled with water is struck a sharp blow, the bottom will

fall out of the bottle. If the bottle had been filled with air, the stopper would have gone a bit farther into the neck of the bottle and part of the force would have been used up in compressing the air, but the bottle would not have broken. We conclude that gases can be easily compressed into less space, but liquids cannot.



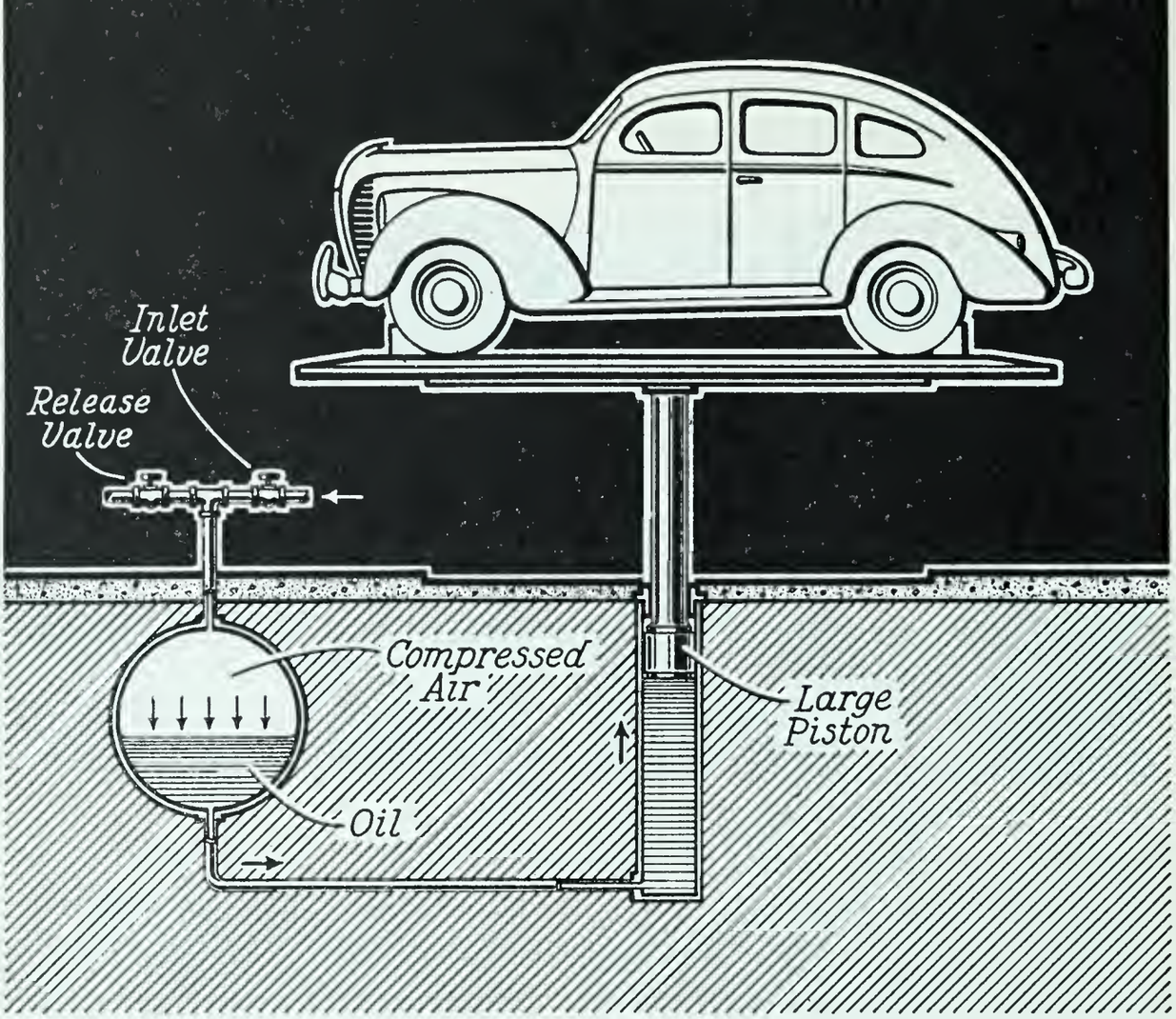
The hydraulic press is used to multiply force.

The hydraulic press illustrates the usual manner in which a liquid is used to transmit pressure. Since the pressure applied is transmitted undiminished to every portion of the surface that the enclosed liquid meets, an extremely great mechanical advantage can be obtained. Pressure means force per unit area—for example, pounds per square inch. Thus the total force in any part of the press depends upon how much surface there is for the pressure to act against. A pressure of 20 pounds per square inch acting on a surface of 100 square inches would exert a total force of 2,000 pounds. In the diagram, notice that the area of piston P_2 is purposely made much larger than that of piston P_1. The force exerted upon P_2 becomes as many times greater than the force applied to P_1 as the area of the cross section of P_2 is greater than that of P_1. Stated as a formula, we see that for the hydraulic press

$$\text{ideal M.A.} = \frac{\text{cross-section area of large piston}}{\text{cross-section area of small piston}}$$

Hydraulic presses are used for baling cotton and paper, obtaining oil from seeds, squeezing juice from fruits, punching holes in steel plates, pressing cold steel, and lifting great weights. The liquid used in the presses is sometimes oil rather than water. Oil has a low freezing point and keeps the moving parts lubricated.

Other devices which make use of the same principle for transmitting pressure and multiplying force are the hydraulic jack, hydraulic brakes, such as are commonly found on automobiles, and hydraulic elevators. A hydraulic system is commonly built into dentists' and barbers' chairs for raising them.



Most service stations are equipped with hydraulic lifts which operate as explained by this diagram.

• POWER AND WORK

Generally speaking, power must be transmitted from the place where it is developed to the place where it is used. In the automobile, you will recall, a transmission system relays the power from the engine, where it is developed, to the rear wheels, where it is utilized. In hydraulic machines, liquids replace the gears and shafting used in the automobile for the transmission of power. When power is transmitted by hydraulic pressure, gas pressure, or electricity, the power developed by one machine is used to operate a second machine. Locomotives driven by compressed air are often used in mines instead of other kinds which would create objectionable exhaust gases or be more likely to ignite the explosive mixtures of gases which sometimes form in mines. The air to be used as motive power is compressed by large compressors, which may be outside of the mine itself, and is piped to tanks along the haulage paths within the mine. The locomotives stop at these tanks to replenish their supply of compressed air. Likewise with electricity and hydraulic power: one engine generates the power, and another engine uses it to produce motion.

In the second general type of power transmission, the motion

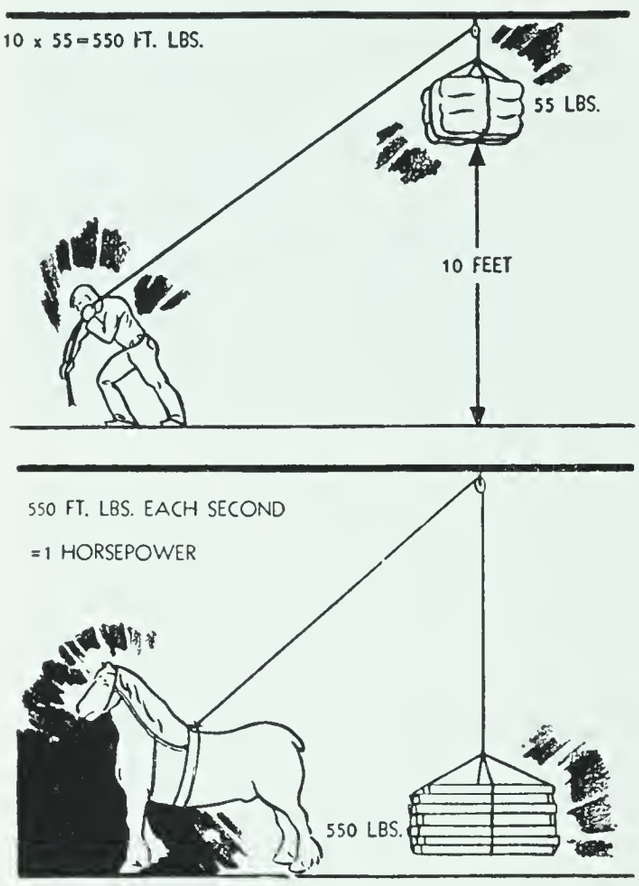
developed by the original engine is relayed mechanically to other points where it is used to operate other machines. The mechanical transference of the motion is accomplished by such devices as shafts, gears, pulleys joined by belting or ropes, sprockets connected with chains as in the bicycle, eccentrics, cranks, connecting rods, and other lever systems. These devices may be used either singly or in combination. By arranging for the proper mechanical advantage, speed or force can be multiplied as desired. Thus the motion is transmitted to the point where needed instead of being produced there by means of another engine.

The words "power" and "force" do not have the same scientific meaning, although they are commonly used as if they did. For example, we say that engines require power to drive them when it would be more accurate from a scientific viewpoint to use the word *force* instead of power. Force, you recall, is simply a push or a pull. When force acts through a distance, work is accomplished.

When a hoist lifts a 100-pound weight vertically a distance of 10 feet, it does 1,000 foot-pounds of work. Note that the hoist has accomplished the same amount of work no matter how much time passed while the work was being done. Work done, therefore, is independent of time; that is, an expression for work makes no mention of time.

In deciding how to perform a given task economically, time is an important factor. Through the increased use of machines in the electric-light-bulb industry, the average production of each worker increased from twenty thousand bulbs a year to one hundred thousand bulbs a year within a decade. Machines thus increased the power of each worker fivefold. In the textile industry today, it is estimated that one man can produce as much cloth in a day as forty-five thousand men could in the period just following the American Revolution. The speed of modern machinery accounts for most of the differences in production.

Obviously, in any comparison of machines we need a unit which will tell us how fast they can perform the tasks for which they have been designed. "Power" is the term which scientists have adopted to include the time element when work is done. Power is defined as *the time rate of doing work, or of transforming or transferring energy*. To say that a hoist did 1,000 foot-pounds of work when it lifted a 100-pound object a distance of 10 feet is simply an expression for work; but if the time required were 5 seconds, then we could say that the machine was working at a rate of 200 foot-pounds per second—an expression of power. If two machines per-



Courtesy General Motors Corporation

form the same task, the one which does it in the lesser time demonstrates the greater power. The power developed by any machine will vary somewhat as it performs different tasks.

Scientists have adopted the "horsepower" as the unit for measuring power developed. James Watt invented the term to impress upon prospective customers how many horses his steam engine would replace. He calculated that a horse could do about 33,000 foot-pounds of work per minute. Although the ordinary horse can work at only about three-fourths of this rate, 1 horsepower is the above rate which Watt obtained experimentally using a Clydesdale, an especially strong horse. Thirty-three thousand foot-pounds per minute is, of course, exactly the same rate as 550 foot-pounds per second. An average man while running can work for a short time at a rate greater than 1 horsepower, but for work continued over longer periods of time, his rate of working is about $\frac{1}{7}$ horsepower.

Exercises for Problem Study and Review

1. Why do we use machines? Do they save work? Do they save energy? Explain fully.
2. Why is the ideal M.A. of a machine always greater than the actual M.A.? How may they be made to agree more closely?
3. Do machines violate the principle of conservation of energy? Explain.
4. Is friction a help or a hindrance? How can friction be decreased? Increased?
5. Explain why the ideal M.A. of the inclined plane cannot be less than 1.
6. What is the advantage of placing the load as near the wheel of the wheelbarrow as possible?
7. Can a 160-pound man lift a 200-pound weight with a single, fixed pulley? Explain.

8. Is the rate of flow of a siphon affected by (1) the diameter of the tubing? (2) The atmospheric pressure? (3) The lengths of the two arms? (4) The smoothness of the inside surface of the tubing? (5) The density of the liquid? Explain each case.

9. Study the illustration of pulley systems on page 183, and calculate for each one (1) the ideal M.A.; (2) the actual M.A.; (3) the efficiency.

10. A man wishes to move a heavy safe by using an 8-foot crowbar as a second-class lever. He must overcome a weight of 480 pounds. If the safe rests against the crowbar at a distance of 1 foot from the end, what is the M.A.? What effort force is needed?

11. Refer to the illustration of the inclined plane on page 184 and calculate the ideal M.A. and the force necessary to move the ball up the plane if friction is neglected. If, in actual practice, a force of 150 pounds is needed to move the ball up the plane, what is the machine's efficiency? The length of the plane is 12 feet.

12. A derrick with a crank and axle and a single fixed pulley is used to unload heavy boxes from a boat. What force must be exerted on the crank to raise a box weighing 500 pounds, if the crank is 2 feet long and the axle 6 inches in diameter? Neglect friction.

13. What weight is lifted by a builder's jackscrew with a pitch of ¼ inch when a force of 10 pounds is exerted at the end of the handle which circumscribes a circle 3 feet in diameter? What is the ideal M.A. of this machine?

14. A 165-pound man climbs a vertical ladder to a height of 20 feet. How much work does he do? If he climbs the ladder in 10 seconds, what horsepower does he develop? How much potential energy does he have at the top of the ladder?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. Some people feel that the rapid development of machines, particularly those applicable to warfare, is detrimental to society, and they have suggested that perhaps a five-year "holiday" during which no new ones could be patented or put in use would be a good thing. What do you think of this proposal?

2. "Good drivers are born, not made." Debate this proposition.

3. Two girls were decorating for a party and wished to put some balloons up around the room. One of them inflated a balloon, tied it tightly, and rubbed it briskly on the rug. When she placed it against the wall, it stayed as if by magic. "What makes it stay?" asked the second girl. How would you answer her question?

4. A hard-rubber or plastic comb stroked through the hair becomes electrically charged. How would you find out whether its charge is

positive or negative? Why doesn't a metal comb become charged?

5. Outline a systematic scheme for locating the trouble when your automobile engine suddenly stops running.

6. A water solution of zinc chloride is placed in a crock, and two carbon electrodes connected to a storage battery are introduced. Predict what will happen when the current is turned on. Draw a labeled diagram as part of your explanation.

7. One end of a strong bar magnet is held near the clear glass bulb of an electric lamp while it is operating on the regular house current. The filament is seen to begin vibrating strongly. How would you explain this observation?

8. Which gives the greater voltage—an ordinary automobile storage battery, a group of five dry cells connected in parallel, or a group of five dry cells connected in series? Why are dry cells not used for ignition purposes in automobiles?

9. A man wishes to operate a home-workshop lathe by transmitting power by belting from an electric motor to a countershaft and then to the lathe, so that the latter operates at about one-third the speed of the motor. How can he accomplish his purpose?

10. Some motorists deflate their tires somewhat during rainy weather, thus giving more contact surface between the tires and the road. Evaluate this practice as an aid to quicker stopping. What science principle is involved?

11. A summer cottage along a clear mountain brook is situated about 10 feet above and 40 feet back from the stream. The owner wishes to pipe water from the stream into the cottage for purposes other than drinking. Could he do this by (1) a siphon? (2) A lift pump? (3) A force pump? (4) A hydraulic ram? Explain how or why.

12. An old dry cell gives very nearly the same E.M.F. as a new one but will not deliver much current. Why?

13. The wiring installed today in most new houses branches, with several rooms connected to each branch and each branch protected by separate fuses. What is the reason for this arrangement? How would you know which fuse to replace if one "burned out"? How could you find out which rooms were connected to the same circuit?

14. When connected to a 115-volt line, an electric range draws a current of 20 amperes. What electrical power is supplied to the range? How much heat will it produce in 1 hour? What would be the cost if the electric rate for heating is three cents per kilowatt hour?

15. Sir Humphrey Davy, an eminent English chemist, when asked what he considered his greatest discovery, replied, "Michael Faraday" (who had been his laboratory assistant). Why do you think he said this?

16. Distinguish between scientific discoveries and inventions. Give several examples of each from this unit.

17. Has electricity promoted the growth of large cities, a movement of population away from large cities, or both? Explain.

18. Why does gasoline explode in the gas engine but burn quietly in a gasoline stove?

19. Why is it necessary to have a cooling system for gasoline engines but not for steam engines?

20. If tomorrow is an average day for automobile fatalities, how many persons will then be killed in the United States in motor accidents?

21. What should you do now to decrease your chances in the future of being (1) killed in an automobile accident? (2) Responsible for an automobile accident which will hurt or kill someone else?

22. Do you think that your local, state, or national officers could do more than they are doing to reduce fatalities to motorists and pedestrians? If so, give specific recommendations.

23. Why is the cable from an automobile storage battery to the starting motor so heavy? Where does the other cable connect? Why?

24. The heating element of an electrical heating appliance discolors when put into use. How do you account for this?

25. It has been said that the shoe-repair business is founded upon the results of friction. Explain. Can you name any others in this same category?

UNIT WORD LIST

power
machine
efficiency
work
energy
force
kinetic energy
potential energy
water head
generator
turbine
horsepower
reciprocating motion
rotary motion
inertia
internal combustion engine
clutch
transmission
differential
electron
magnet
proton
conductor
insulator
electromotive force (E.M.F.)
potential difference (P.D.)
voltage
amperage
ion
voltmeter
ammeter
galvanomoter
armature
slip rings
commutator
magneto
electromagnet
alternator
ohm
resistance
watt
kilowatt
kilowatt-hour
foot-pound
electrolyte
nonelectrolyte
acid
base
salt
electrolysis
anode
cathode
electrode
electroplating
cell
battery
relay
brush
transformer
fuse
rheostat
condenser
output
input
coefficient of friction
pressure
eccentric
mechanical advantage (M.A.)

INTERESTING THINGS TO DO

1. Station yourself at a busy intersection in your neighborhood where there is a blinker light or stop street. Make note of all traffic violations or hazardous practices by motorists and pedestrians during a 1-hour period. Tabulate your results and discuss them before the class.

2. If your school does not already have one, organize a Good Drivers' Club and do your bit for greater safety on our streets and highways. Write to the National Safety Council, Washington, D. C., for pamphlets and other useful materials.

3. Collect a group of advertisements for automobile storage batteries. Summarize the claims made and evaluate each one in terms of scientific facts and principles.

4. Make a diagram showing how you could wire a doorbell so that it could be rung by push buttons at both the front and back doors.

5. Determine the ideal mechanical advantage of the sprocket wheels on a bicycle.

6. Visit an electric-power generating station and report your observations to the class.

7. Visit a central plant for the generation and distribution of steam to consumers for heat and power. Report to the class on the science ideas that you see applied.

8. Outboard motors are known as two-cycle engines. Find out how they work, make whatever drawings you think helpful, and present your findings to the class.

9. Examine the motor of an electric clock to find out what type of motor it is and how it operates.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Perpetual-motion machines.
2. Fluid transmissions for automobiles.
3. How the accumulation of static electricity is prevented.
4. The construction and use of the Edison battery.
5. How water-pressure and air-pressure gauges work.
6. Devices and methods of gaining protection against lightning.
7. Requirements of the local electrical code.
8. How the induction, or "squirrel-cage," motor works.
9. How A.C. is changed to D.C. in a battery-charging shop.
10. What kind of current is used for electric trains, trolley busses, or streetcars in your vicinity, and how it is obtained.
11. The researches, discoveries, and inventions of eminent scientists whose work relates to topics within this unit—Oersted, Faraday, Henry, Ampere, Edison, Franklin, Steinmetz, Watt, Diesel, Kettering, and others.

12. How hospitals, hotels, and telephone exchanges make provision for getting electric power when that from the electric company is temporarily discontinued.

13. The reasons for the seeming inconsistency in that the rating for household electric lamps are stated in watts; that for automobile lamps in candle power; that for flashlight lamps in voltage.

14. How the Delco-light system works.

INTERESTING BOOKS TO READ

Bryan, G. S., *Thomas A. Edison, the Man and His Work.* Alfred A. Knopf, Inc., New York, 1926. Every American boy and girl should know about this great inventor. This is an interesting book to use for this purpose.

Chase, Stuart, *Men and Machines.* The Macmillan Company, New York, 1929. One of the best references on the Machine Age—how it came about and what it is doing to us.

Hodgins and Magoun, *Behemoths.* Doubleday, Doran and Company, New York, 1932. The story of the development of power and of the great names associated with it.

Jordanoff, Assen, *Your Wings.* Funk and Wagnalls Company, New York, 1940. An authoritative and very well-written discussion of modern aviation. Comprehensive and unusually well illustrated.

Leonard, Jonathan N., *Tools of Tomorrow.* The Viking Press, New York, 1935. An interesting discussion of the relation of science to engineering and of discovery to invention.

Morgan, Alfred P., *The Pageant of Electricity.* D. Appleton-Century Company, New York, 1939. Tells the story of the development of electrical science and its applications and of the great men who helped it along.

Neill, Humphrey B., *Forty-eight Million Horses.* J. B. Lippincott Company, Philadelphia, 1940. A real success story in one field of applied science, describing the rapid progress made in the development of electricity since Thomas A. Edison opened the Pearl Street station. Social implications are directly stated or inferred.

Williams, Sidney J., and Charters, W. W., *Safety.* The Macmillan Company, New York, 1940. Safety education coordinated with the study of the basic sciences.

urora Borealis Gives City a Show As Sun Spots Disorganize Radio

splay of Northern Lights Unparalleled in Years Seen From Buffalo to Virginia— Dodger Fans See Red as Broadcast Fails

100,000,000 Worth of Metal s Sought in Arizona Meteorite

INSLOW, Ariz., Oct. 11.—What e geologists believe to be a for- in nickel, which plunged into earth from outer space in a t meteorite near Canyon Diablo, or maybe the head of a comet, the crater is almost incredible. Nevertheless scientific evidence now points to this explanation. Around its sides there are countless little nickel-iron meteors. Rocks have been pulverized

FE HELD LIKELY ON PLANET VENUS

ncer Jones, Astronomer oyal of Britain, Says It May Be Just Starting

LION YEARS BEHIND US

rs, He Asserts in Report of mithsonian Institution, Is Like Earth in Old Age

UNIT THREE — THE SKY

Scientists Leaning To New Calendar Of Even Quarters

Every Year Would Start on Sunday Under Proposed Plan

BOSTON, March 19.—A proposal that would include a couple of world-wide holidays is "in the lead for nomination" among scientists working toward a revision of the present calendar, a Boston astronomer said today.

But only one would come early—Year's End Day.

The other one—Leap Year Day—would come only in leap years.

Committees in practically every

STAR GAZING?

Daylight Saving Time In Effect This Morning

Daylight saving time went into effect at 2 a.m. today, when clocks were set ahead one hour in New

Sun-Spot Tornado Disrupts Cables, Phones and Telegraph for 5 Hours

Electrical Disturbance Plays Havoc With the Short-Wave, 1,000,000 Easter Messages and Police and Press Teletypes

Vhy Build Big elescopes?

Scientific "Mystery" Is Cleared Up

azing Meteor, sible 300 Miles, rops in Canada

LEVELAND, July 11 (A. P.).—A or of tremendous size, visible for dreds of miles, streaked north ss Lake Erie tonight and disap ed in a burst of light over or in

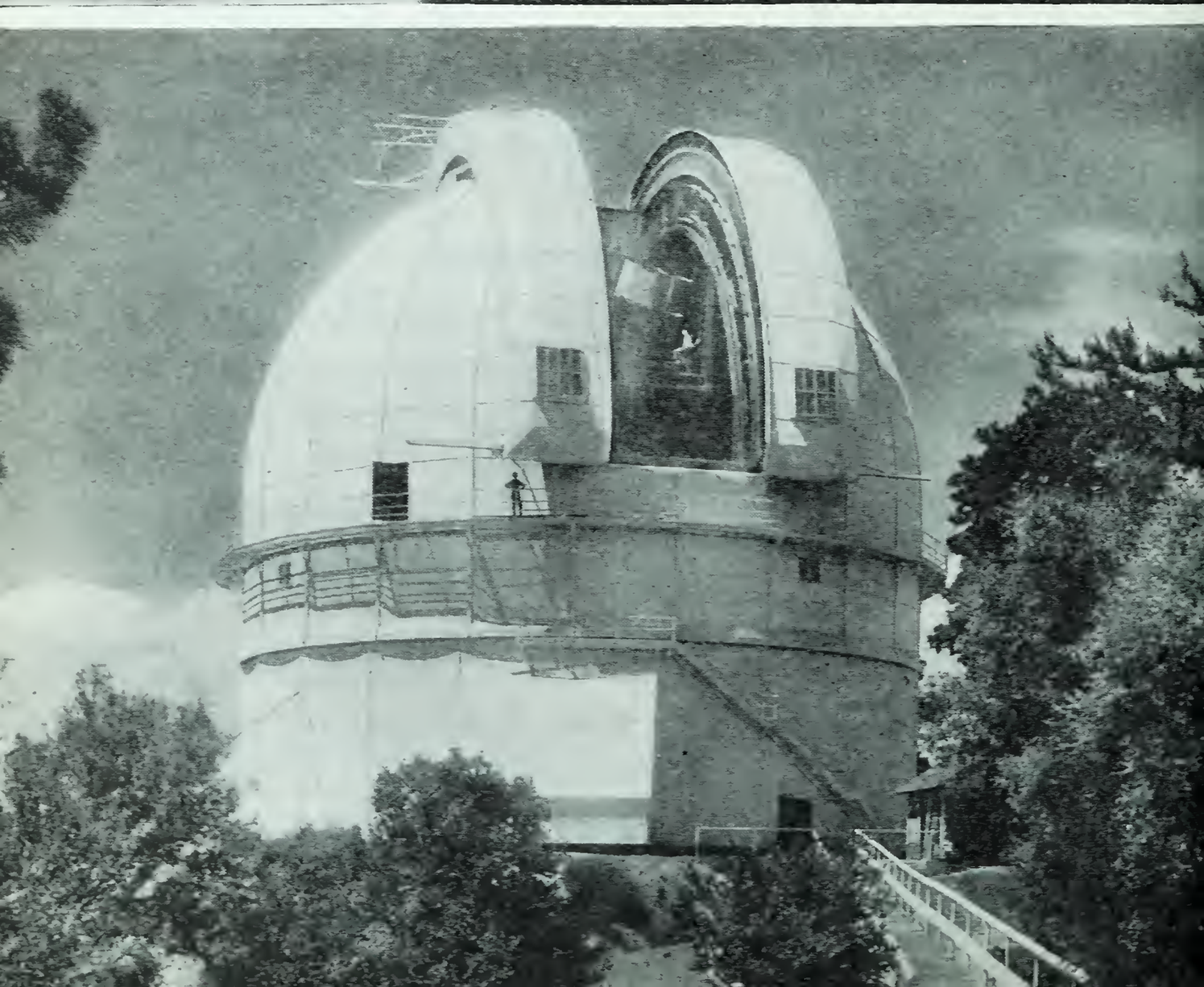
Comet Is Slipping Away

New Year's Night Picked for Best of Final Shows, But Dust Off That Glass

Last call for a look at Cunning- a curve to the south, from near

Evidence of Plant Life on the Planet Mars Is Announced by an American Astronomer





Unit Three

THE SKY

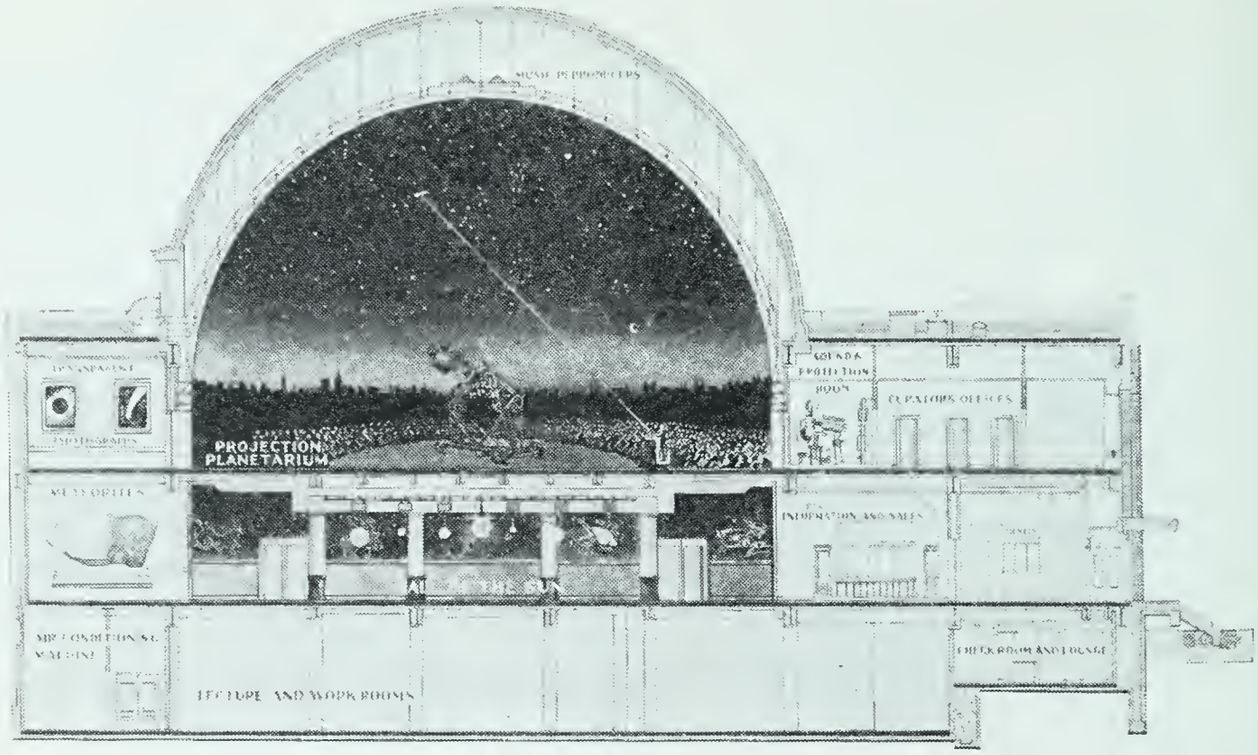
From earliest times, man has been an astronomer. Upon looking out into the clear night sky, even the most primitive men must have experienced sensations of awe and wonder as they watched the celestial scenery go by. Night after night throughout the ages, stargazers have been able to see an almost jet-black sky studded with twinkling stars. Today, more than ever before, there is a widespread interest in astronomy. Radio programs, magazines, and newspaper articles give recent information about the cosmic world. Many persons have taken up astronomy and telescope making as hobbies. Public interest in astronomy has justified the construction, at great cost, of several projection planetariums—special theaters for unfolding the interesting and instructive drama of the skies.

There are also practical, everyday applications of astronomy. Clocks and calendars, for example, devices that we take for granted without questioning their origin or how they operate, would be impossible without astronomical knowledge. Positions on the earth's surface must be located; ships at sea and aircraft aloft must be navigated. All of these adjustments, whether we realize it or not, are made in terms of astronomical knowledge with scientific instruments.

In many respects, how we think and what we believe because of our knowledge of the sky are more vital than the adjustments that seem more practical. More so in the past but to some extent even today, belief in astrology, resulting from ignorance of the facts of astronomy, has shackled man with unreasonable fears and superstitions. Happily, the results of astronomical investigation have largely changed this situation; the mind of man has been liberated and he has gained confidence in scientific methods.

In the unit problems that follow, we shall consider in greater detail the knowledges, methods, and instruments of man, the astronomer. Then we shall see how knowing about these things may influence our thinking and our attitudes and how they are of value in helping man solve some of the problems of everyday living.

Photos courtesy New Departure (top); Mount Wilson Observatory (bottom)



Courtesy American Museum of Natural History

You are indeed fortunate if you live near a planetarium. The lecturer controls the amazing projector which can reproduce within a few minutes the changes which take place in the sky during a thousand years or more. This interesting sketch shows a cross section of the building which contains the planetarium.

Problem 1: What has man learned about the earth as a heavenly body?

A person thinking about the earth for the first time would most likely decide that it is motionless and is located at the center of the rotating sphere of the sky. But, as is often the case, the unaided senses would have led to a false conclusion. Investigations made with the help of astronomical instruments have provided convincing proofs that the sky is only a seeming sphere and that the globe of the sky does not rotate—it is the earth that rotates. Because the earth rotates and carries us around with it, the sky overhead seems to rotate. Thus it is the *real* motion of the earth that causes the *apparent* motion of the sky.

• OUR ROTATING SPHERE

Almost all people of early time thought that the earth was flat except for mountains, valleys, and other surface features. Some people thought of the earth as being oblong, while others pictured it as a circular disk with the sky overhead closing down

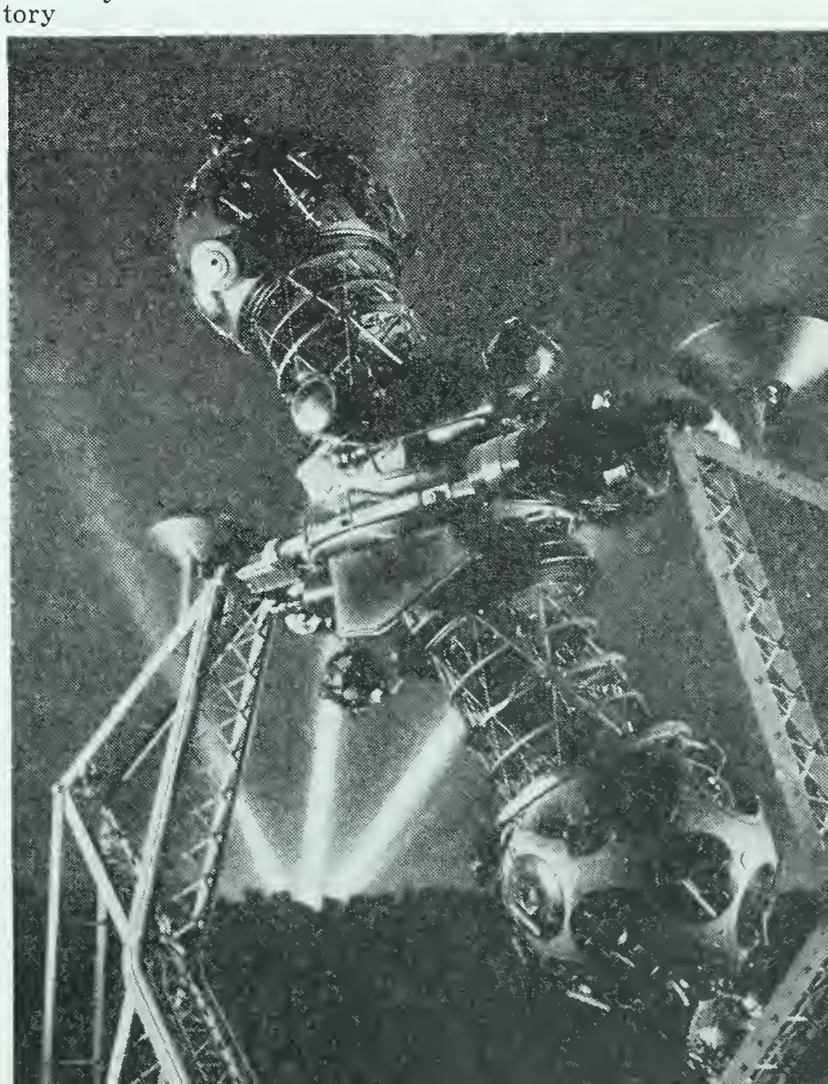
and touching its rim like a blue bowl inverted over a flat plate. Many people believed that a huge moat of water surrounded the earth. Relatively few people believed the earth to be round like a ball, although this belief was held by certain Greek philosophers as early as 400 B.C.

There are many proofs that the earth is very nearly a sphere. When a ship puts out to sea, the lower part disappears first and the topmost part last. The voyages of Columbus, Magellan, and others furnished final and convincing evidence that the earth is round. An eclipse of the moon is caused by the shadow of the earth falling on the moon, and, since the edge of this shadow is always part of a circle, we conclude that the earth is shaped like a globe.

How would you measure the size of the earth? You might suggest flying an airplane around the earth and keeping track of the number of miles flown. But how could the measuring have been done more than two thousand years ago? The size of the earth was estimated at that time with surprisingly accurate results. It was noted that at noon on the longest day of the year, the sun was 7.2° south of the point directly overhead as observed from Alexandria, Egypt. Observers at another town five hundred miles farther south reported that the sun was directly overhead at noon on the same day. Reasoning from these two observations, a distance of five hundred miles caused the sun to shift its apparent position by 7.2°. Then to cause a shift of 1 degree, one would have to travel only about 70 miles ($500 \div 7.2$). Since there are 360° in a circle, a great circle around the earth would then measure about 25,000 miles (70×360). It follows that the diameter of the earth would be about 8,000 miles ($25{,}000 \div 3.1416$). More accurate measurements indicate that the diameter of the earth

This is the projection instrument of a planetarium.

Courtesy American Museum of Natural History



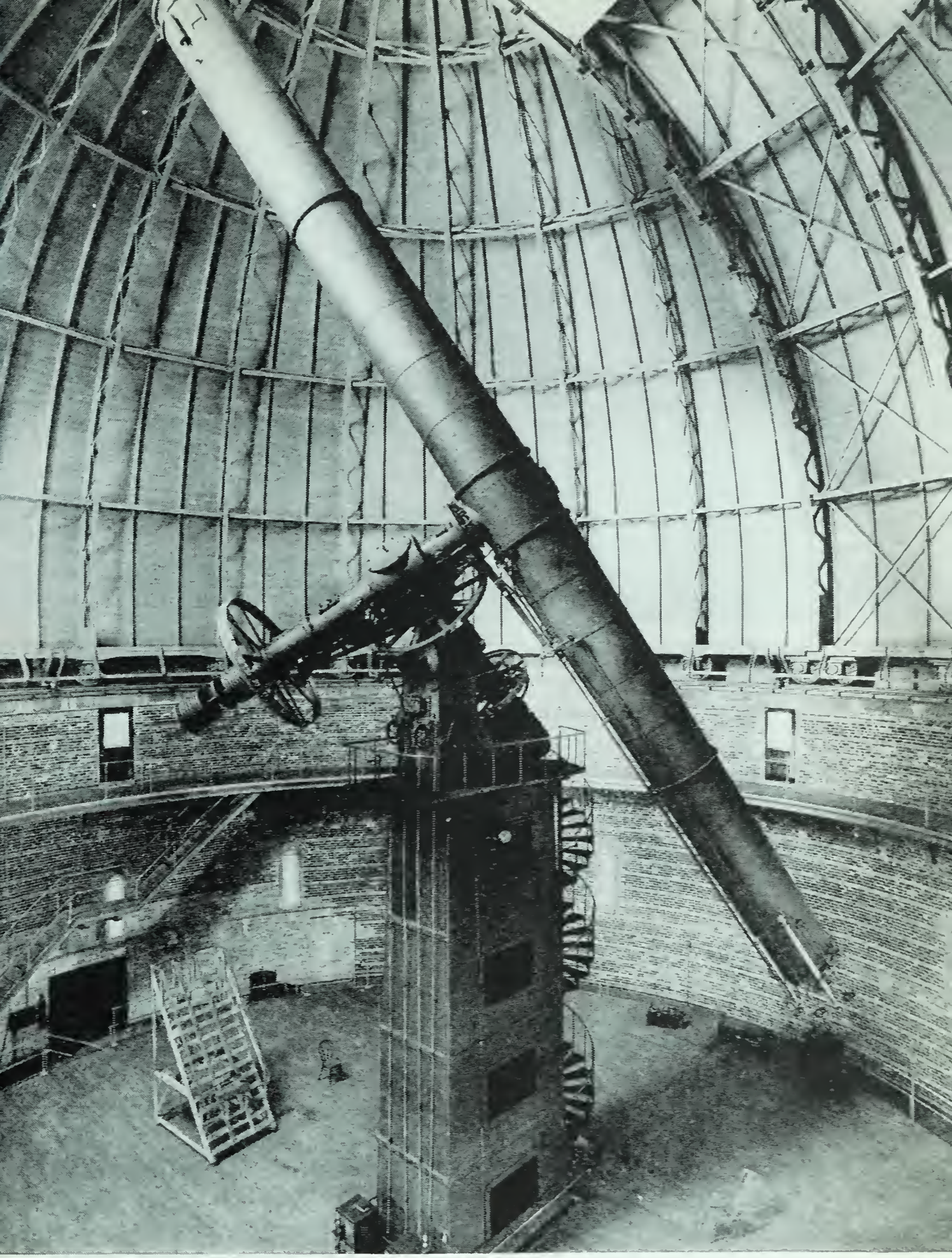
from pole to pole is 26.70 miles less than at the equator. This fact shows that the earth is slightly flattened at the poles and that it bulges at the equator.

The cause of the earth's bulging waistline is centrifugal force. This force is seen in operation when mud flies off in a straight line from a spinning automobile wheel. Since all centrifugal force results from rotary motion, we conclude that the earth is a spinning globe. Man does little or nothing by way of adjustment to the earth's centrifugal force, but he has found it very desirable to apply the same principle in many of his machines. Centrifugal force caused by the spinning of the earth is sufficient to cause most rivers to run uphill. At the equator, the surface of the earth is, on the average, about 13.5 miles farther from the center of the earth than at the poles; therefore, all rivers that flow toward the equator really flow uphill. If the earth stopped rotating, these rivers would suddenly reverse their direction of flow and rush toward the poles.

• OUR REVOLVING EARTH

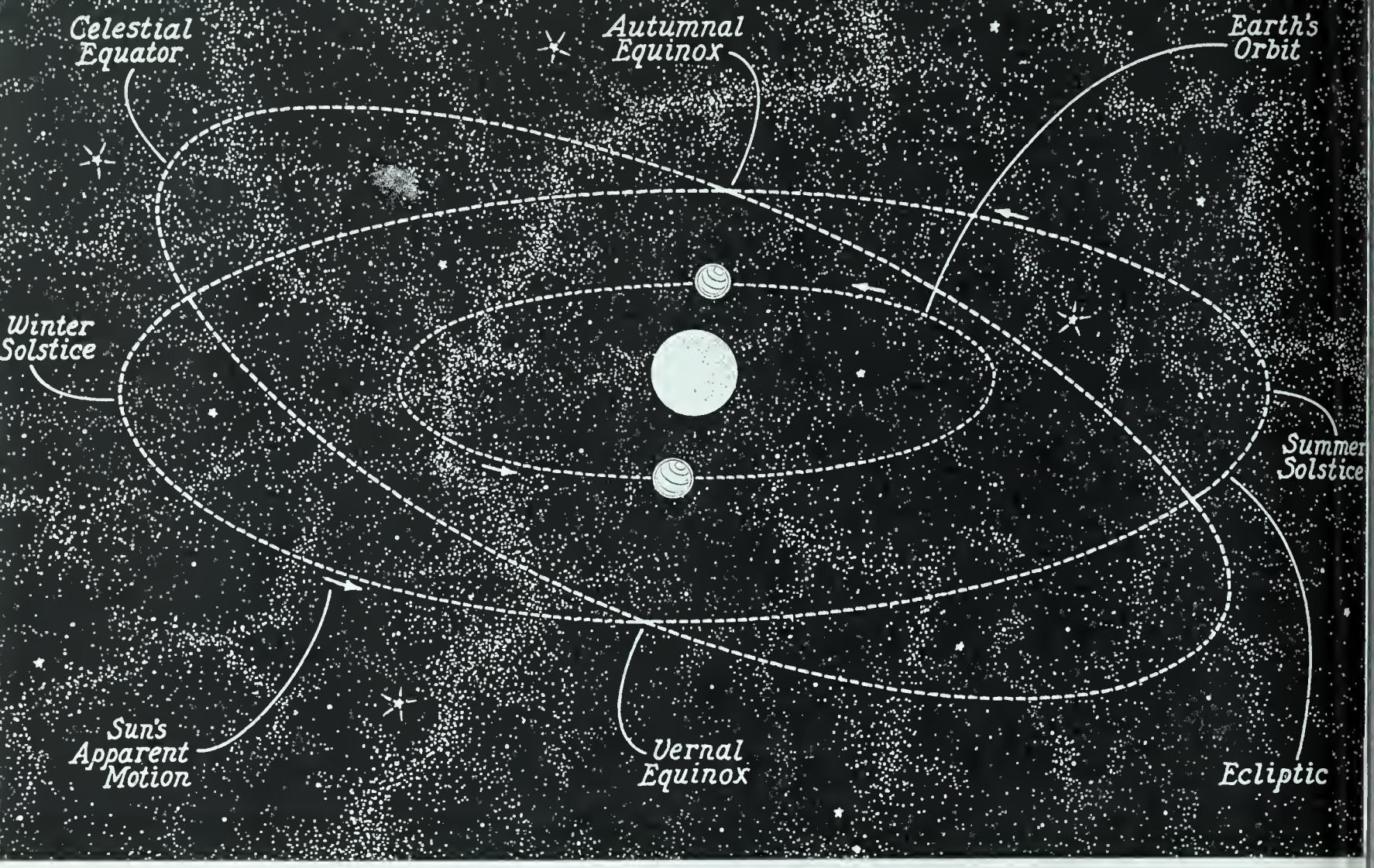
Each night stars rise in the east, circle overhead, and set in the west because of the earth's rotation. If we time our observations carefully, we find that the stars rise four minutes earlier every day; that is, the stars which do rise and set are a little higher in the sky each night when the sun sets than they were the night before.

The apparent westerly parade of the constellations during the year results from the earth's revolution around the sun. Let us pick out a familiar constellation, such as Leo the Lion, and note how it seems to change its position during the course of a year. Imagine that it is visible just above the eastern horizon right after sunset on a particular night. One week later it will be seen a little above the horizon as it comes into view after sunset. When a month has passed, it will stand noticeably higher in the sky at this time of day. Finally, Leo will catch up with the sun, and they will rise and set together. Then the constellation passes the sun and thereafter will rise and set before it. During this time the constellation will be overhead during the daytime and will be invisible because stars cannot be seen during hours of daylight. After another period of time, Leo will be far enough ahead of the sun to be again visible on the eastern horizon just after the sun sets in the west. One year will have passed; not only Leo, but all the constellations, will have marched westward once around the sky.



Courtesy Yerkes Observatory

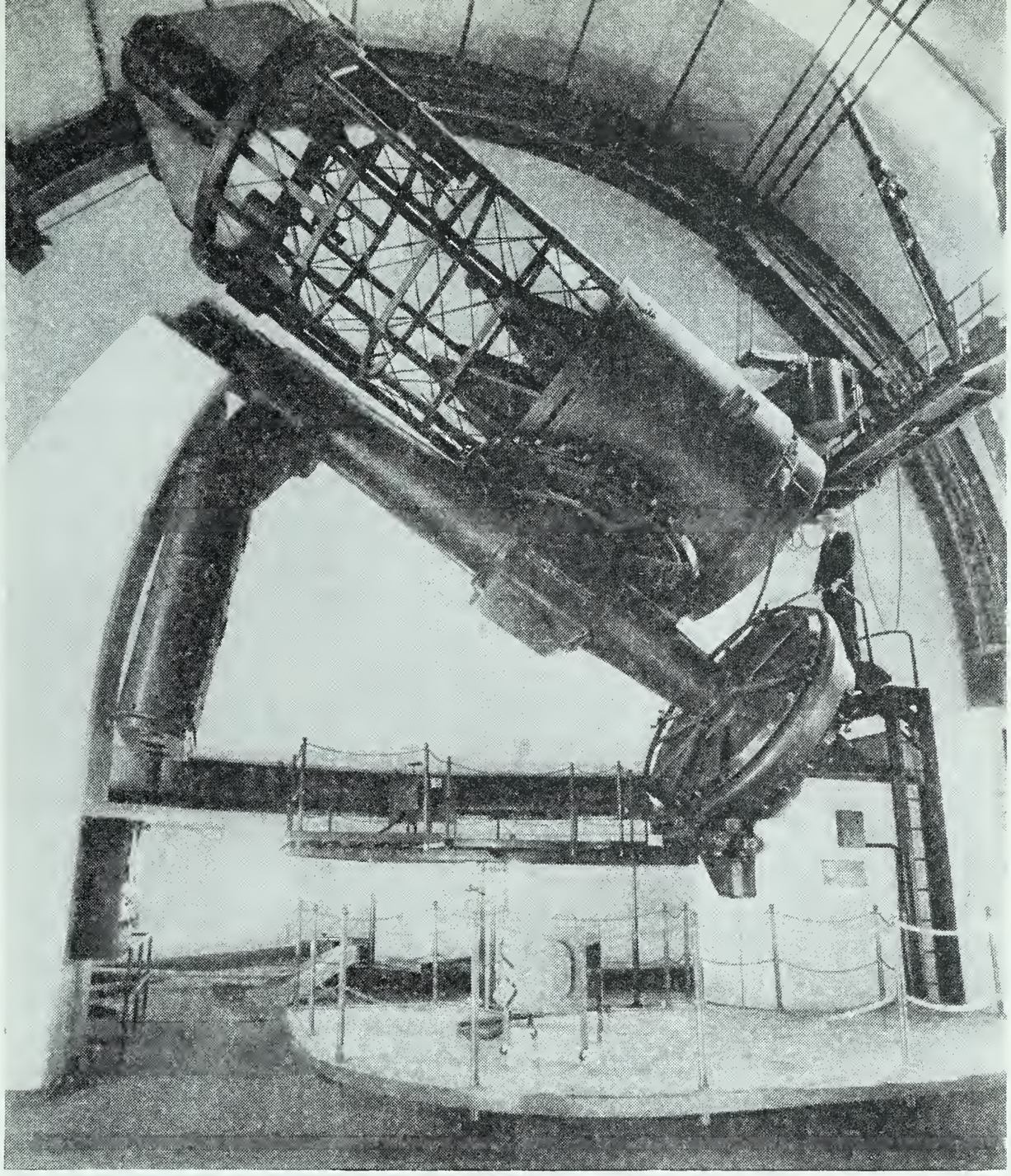
The forty-inch refracting telescope at the Yerkes Observatory, Williams Bay, Wisconsin, is the largest of its kind in the world. It is sixty-two feet long and its moving parts weigh twenty tons. By magnifying forty thousand times more than does the unaided eye, it enables astronomers to view the moon as if that satellite were only sixty miles from the earth.



The earth's equator is tilted to the plane of its orbit. Since the celestial equator is a projection of the earth's equator outward to the sky, it is similarly inclined. The ecliptic and the earth's orbit lie in the same plane; therefore the celestial equator is tilted with respect to the ecliptic.

To visualize how this happens, set a lighted lamp on a table located at the center of a room. Now look at the lamp against its background as you walk around it in a circle. Notice how the lamp (the sun) and the background (the constellations) seem to move with respect to each other. The background of walls, windows, doors, and wall furnishings seems to be moving toward you, while the lamp seems to be circling the room in the same direction that you are going. In similar fashion, the sun makes a yearly circuit of the sky from west to east because the earth revolves around the sun once each year in that same direction.

The apparent annual path of the sun is called the ecliptic. The ecliptic is a circle on the globe of the sky. The sun is always on the ecliptic. If we extend the earth's equator outward upon the globe of the sky, we have a second circle, called the celestial equator. The fact that the sun moves north of the celestial equator in summer and south of it in winter shows that these two great circles are tilted with respect to each other. Therefore, they must cross each other at two points. In the spring the sun climbs to the point where the ecliptic crosses the celestial equator. We call this the vernal equinox. The date of this occurrence is on or about



Courtesy Yerkes Observatory

Above is the eighty-two inch reflecting telescope of the MacDonald Observatory.

March 21. The sun continues to climb until it reaches the highest point of the ecliptic, called the summer solstice, 23½° north of the celestial equator. This is the place of the sun on or about June 21, the longest day of the year for us in the northern hemisphere. The point where the sun again crosses the celestial equator on its descent is called the autumnal equinox, and the lowest point that it reaches on the ecliptic—23½° south of the celestial equator—is the winter solstice. The sun stands at these points successively on or about September 23 and December 21. The dates given vary somewhat from year to year because of our leap-year arrangement.

Careful measurements show that the apparent diameter of the sun as viewed from the earth varies slightly during the year. This suggests that we must be nearer to the sun at some times than at

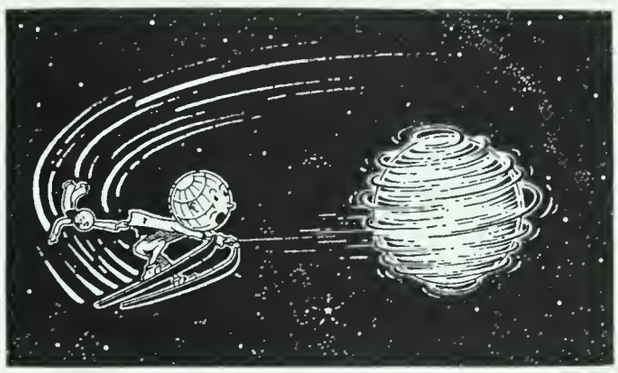
others. This would not be true if the earth's path around the sun were a perfect circle with the sun at its center. The sun appears largest about January 1 and smallest about July 1; therefore, we must be nearer to the sun in January than we are in July. At first thought, the conclusion that the sun is nearer in winter than in summer may be quite surprising. Remember that when it is winter in the northern hemisphere it is summer in the southern hemisphere. Hence we conclude that the varying distance of the sun does not cause the seasons. The sun's distance varies from 91,300,000 miles to 94,500,000 miles; the average distance is almost 93,000,000 miles. The variation in the distance from earth to sun is due to the fact that the earth's orbit is a slightly flattened circle, called an ellipse, with the sun at one focus.

If a pointer is drawn representing the line of vision from the earth to a star above the earth's orbit and is extended to the more distant stars beyond, it can be seen that, as the earth wheels around in its orbit, the end of the pointer will describe a little orbit for the near-by star on the background of the sky. The apparent motions of the stars in little orbits is much too small to be noticed without the aid of a telescope, but astronomers have detected this type of star motion and have drawn the apparent orbits thus observed. Each is somewhat elliptical and is truly a miniature replica of the earth's orbit around the sun. Therefore we have definite evidence that the earth revolves around the sun and that the orbit of the earth is elliptical.

We have considered two motions of the earth. One is its daily rotation on its axis; the other is its yearly revolution around the sun. These motions of the earth cannot be detected directly by us living on the earth, and it is only when we begin to wonder about the causes of the turning sun, stars, and sky overhead that they become clear. Let us summarize the *real* motions of the earth and the *apparent* motions of the sky which result.

The earth rotates from west to east once each day. This motion causes the apparent daily rotation of the sky and the heavenly bodies from east to west, and it brings about the alternation of day and night. Another consequence of the earth's rotation is the bulge at the equator.

The earth revolves around the sun from west to east once in about 365¼ days. This motion causes the apparent westward march of the constellations around the sky and the apparent eastward journey of the sun around the ecliptic completed in a year. Since the equator of the earth is tilted at 23½° to its orbit and



since its axis points to the same spot in the sky, there are times when the poles tilt toward the sun and times when they tilt away from it. The gradual, progressive change in the direction in which the poles point with respect to the sun brings about the year of the seasons and causes the sun to move north and south throughout the year. The earth's revolution causes the stars to describe little orbits on the background of the sky; this is looked upon as definite proof that the earth does revolve and tells us exactly what shape the earth's orbit really is.

When we think about the motions of the earth, we realize that the earth is taking us through space at a tremendous rate of speed. Since the earth's circumference at the equator is about 25,000 miles and one rotation is completed in about twenty-four hours, objects at this location on the earth are going approximately 1,000 miles per hour. As we approach the poles, we are really getting nearer the axis of rotation, and the velocity gradually diminishes. At the latitude of New York City, the speed of rotation is about 800 miles per hour.

In addition to whirling us around at a rate of several hundred miles per hour, the earth is also carrying us around the sun at an even faster pace. The radius of the earth's orbit is about 93,000,000 miles, which makes the circumference of its orbit about 594,000,000 miles. As the earth completes this journey once a year, its speed is 66,000 miles per hour! This is more than 1,000 miles per minute. If we had a flying machine capable of this speed, we could go from New York to San Francisco in three minutes; five minutes more would find us far beyond the other side of the Pacific Ocean; and in less than twenty-five minutes we would be completely around the globe and back home in New York. At this speed, we would catch up with the sun so quickly that it would appear to be going backwards around the earth—it would rise in the west, pass rapidly overhead, and set in the east.

But the speed of the earth provides no great thrill that we can feel. The earth is so huge and its motions are so smooth and steady, so even and free of vibration and friction, that we do not realize we are moving at all. We can only sit back and think about it; but even this is great fun.

Exercises for Problem Study and Review

1. What observations create the illusion of a rotating sphere of the sky? What is the cause of the apparent rotation of the sky?
2. What were some of the ideas of early peoples regarding the shape of the earth? What knowledge or lack of knowledge led to these conclusions?
3. Give some proofs that the earth is round like a ball.
4. How was the circumference of the earth estimated 2,000 years ago? The diameter of the earth?
5. Describe the cause of the earth's equatorial bulge. Give some other examples of this kind of force.
6. Describe how the stars rise and set night after night throughout the year.
7. What is the cause of the yearly westward parade of the constellations around the sky? How can this fact be demonstrated?
8. What is the ecliptic? The celestial equator? At what angle are these two circles tilted? At how many points do they cross?
9. Tell (a) where the sun is and (b) in which direction it is moving on each of the following dates: (1) March 21; (2) June 22; (3) Septemper 23; (4) December 22.
10. How does the apparent diameter of the sun change throughout the year? What conclusion can be drawn from these facts? What is the average distance from earth to sun?
11. Why do near-by stars seem to move in tiny orbits against the celestial sphere during the course of a year? What shape are these orbits? What conclusion can be drawn from this fact? Can the unaided eyes detect this kind of star motion?
12. Which way does the earth go around the sun? Which way does the sun go around the sky? Which way do the constellations go around the sky? What is the explanation for each of these apparent motions?
13. To what place in the sky does the North Pole of the earth's axis always point? When does it tilt directly away from the sun? Directly toward the sun? When is it at right angles to a line drawn to the sun? What is the result of these changes in the direction the North Pole points with respect to the sun?
14. How fast does the earth rotate? How fast does it revolve? How are these values calculated?
15. Why can we not detect these motions and speeds of the earth?

Problem 2: What has man learned about the solar system?

• EARLY IDEAS ABOUT OUR SOLAR SYSTEM

Ancient watchers of the sky were acquainted with seven bright celestial bodies that move more or less rapidly against the back-

ground of "fixed stars." The sun, the moon, and the five bright planets—Mercury, Venus, Mars, Jupiter, and Saturn—that appear to us to be stars constitute this group of "wanderers." The name, planet, is derived from the Greek word meaning wandering.

Early Greek philosophers noted that these "wanderers" generally moved eastward among the star groups. They also observed that various intervals of time were required for them to circle once around the sky. Since there was nothing whatsoever in their daily experiences to indicate that the earth revolves about the sun, it was perfectly natural for these people to consider the earth as a stationary place from which they viewed the moving picture of the sky. Because of the incorrect notion of a stationary earth located at the center of the universe, it was generally believed that the sphere of fixed stars turned westward around the earth once each day, thus causing the stars to rise and set. The seven wanderers of the sky also shared this daily turning; but, in addition, they moved around the earth in a general eastward direction. It was thought that the length of time required by each of these wanderers for a complete journey was an indication of its distance from the earth. The moon, making a complete revolution about once each month, was nearest; next came Mercury; then came Venus. The sun, circling around the sky once a year, was thought to be fourth in distance from the earth, followed in order by Mars, Jupiter, and Saturn.

This explanation is known as the Ptolemaic theory because it was set forth in great detail by the astronomer Ptolemy in his book, the *Almagest,* which was published at Alexandria in the second century after Christ. The *Almagest* was the accepted authority on astronomy for more than one thousand years, and the Ptolemaic theory, even though false, held sway during that time. Some astronomers as far back as the third century B. C. had suggested that the earth moves; but they could not overcome the authority of Aristotle and Ptolemy, and little or no attention was paid to their ideas.

By the middle of the sixteenth century, the Ptolemaic theory had become extremely mathematical and complicated as attempts were made to alter and to extend it to include new observations. The period of the Renaissance was well under way, and men were becoming increasingly inquisitive about the world in which they lived. In brief, people were at last ready to consider the possibility that *the earth is in motion*—an idea proposed more than one thousand years previously.

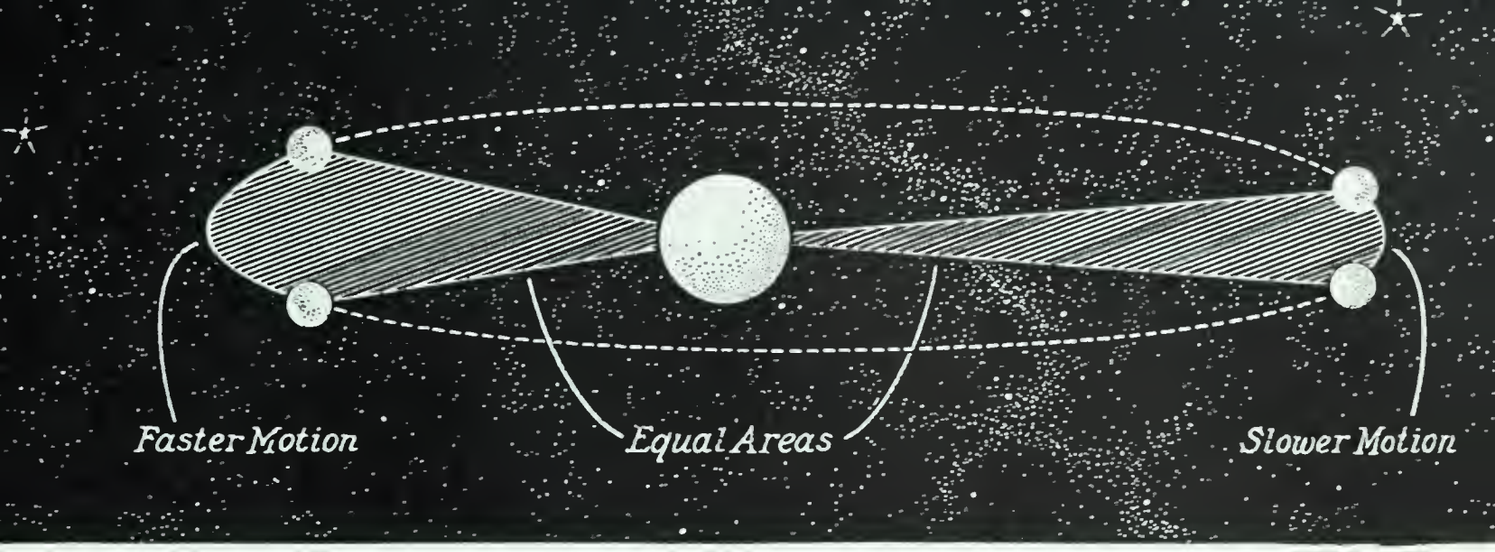
Nikolaus Copernicus was the author of the new theory. His theory was kept secret for twelve years and was not published or generally made known until 1543, the year of his death, because Copernicus feared the consequences that were almost certain to follow. The church and government leaders of the time were so steeped in ancient doctrines and dogmas and were so lacking in open-mindedness that anyone who questioned their beliefs concerning the universe was likely to become the subject of extreme persecution.

In his new system of astronomy, Copernicus designated the sun as the central body of the planetary system and said that the planets revolved about it in circles and with uniform speeds. The earth was given its correct status as one of the planets, and the moon was correctly identified as the satellite of the earth. Copernicus recognized that the planet nearest the sun is Mercury, followed by Venus, Earth, Mars, Jupiter, and Saturn in the order named. Beyond Saturn was still the sphere of the fixed stars, whose apparent daily turning was now explained by the rotation of the earth.

Most astronomers of the time rejected the Copernican theory of a revolving earth because the stars always seemed to be the same distance from each other throughout the year. They reasoned that if the earth were going around the sun, the stars would apparently move apart as we speed toward them and close in again as we leave them behind. They noticed no such change throughout the year and therefore refused to accept the Copernican theory. These objectors failed to realize how extremely remote the stars really are, and they did not see that the changes in their relative positions due to the revolution of the earth would be too slight to be detected by the instruments then available.

One Italian philosopher, Bruno, who strongly favored the Copernican theory, ventured to suggest that if the earth wheels around the sun in a huge orbit and the fixed stars do not seem to change their relative distances from each other and from the earth, then the stars must be extremely remote. This suggestion involving the idea of infinitely large distances was opposed to the Ptolemaic theory, and for his persistence in these beliefs, Bruno was burned at the stake in 1600.

Tycho Brahe, one of the objectors, made observations which later served to strengthen the Copernican theory despite his own disbelief. This came about through Johannes Kepler, one of his students. Upon the death of Tycho in 1601, Kepler came into possession of the records of the planets, which Tycho had kept for



The speed of a planet varies, but a line from it to the sun sweeps over equal areas in equal periods of time.

many years. After much patient study of these records in the hope of discovering just how the planets move, Kepler announced two important laws in 1609:

(1) *The planets revolve around the sun in orbits which are elliptical and all of which have the sun at a common focus.* Thus the ancient and mystical idea that the paths of the planets are perfect circles was laid to rest. Also, the sun and not the earth was definitely established as the center of the planetary system.

(2) *Each planet revolves in such a manner that an imaginary line between it and the sun sweeps over equal areas in equal periods of time.* This rule dispelled the old notion that the planets move with uniform speed. As a planet comes nearer the sun, it moves faster; as it gets farther from the sun, it slows down.

• THE LAWS OF MOTION

What keeps the planets going in their orbits? If it had not been for the work of Galileo and Newton, we might still be searching for the answer to this question and many others related to it.

People have always been inquisitive about the world around them. Before the time of Galileo, they lacked an effective and reliable method of finding the correct answers to their questions. They either consulted the ancient writings of Aristotle for an answer, or else thought of several possible answers and made a guess as to which one was most logical. Scientists call such thinking "armchair philosophy." It is rather difficult for us to understand why they did not "try things out," but at that time the experimental method of investigating questions and problems had not been developed to the point where people generally knew how to use it. Galileo's experimental studies and his resultant findings helped to change this situation.

One commonly accepted belief of the time was that a state of

rest is the natural thing; people believed that objects in motion just "naturally" stop moving and come to rest. Consequently, they found it convenient to think of the earth as stationary rather than as moving, because then they did not have to worry about explaining what kept it in motion. Another accepted belief was that objects falling toward the earth do so at rates of speed regulated by their weights. Aristotle had written it in his great encyclopedia, so who could doubt it? Galileo did. He proceeded to find out experimentally all he could about motion.

Galileo concluded that uniform motion, rather than rest, is the natural state. In other words, if a push or a pull acts on a body to give it a start in a certain direction, the body will continue forever to move in that same direction with the same speed—unless some other force acts to interfere with it in one way or another. Objects ordinarily come to rest because the resisting force of friction interferes with their motion; then another force is required to set them into motion again. But in the vastness of space where there is no friction, the planets wheel in their orbits throughout eternity. And why should they ever stop? Scientific experiments and common experience alike have taught us that it takes force to bring a moving object to rest, as well as to set a stationary object in motion. Galileo recognized this natural property of all bodies, which we call *inertia,* and Sir Isaac Newton described how it operates in his *first law of motion: Every body in the universe continues in a state of rest or of uniform motion in a straight line unless caused to change that state by some external force acting upon it.*

So, you see, the need of an explanation arises only when a body in motion changes its motion either in speed or direction. And this is precisely what is happening to the planets all the time. Their direction is constantly changing, so that, instead of having uniform motion in a straight line, they travel in orbits which are closed curves. This indicates that some force is continually acting on them, and we may well ask what the force is and from where it comes. To find the answer, let us review further some of the findings of Galileo and Newton.

Galileo refused to believe Aristotle's statement that objects of different weights fall to the earth with speeds dependent on their weights. The story that he dropped stones from the Leaning Tower of Pisa to find the truth suggests the experimental approach which Galileo employed. Galileo found that if the effect of air resistance is not considered, freely falling bodies fall at the same

rate regardless of their weights. He recognized that the earth exerts an attraction for objects, thus causing them to fall. This force is called *gravity,* and the weight of an object is a measure of the earth's attraction for it. Thus the earth attracts a 100-pound object with ten times as much force as it does a 10-pound object. Why, then, does not the 100-pound object fall ten times as fast as the 10-pound object? The answer is easy—since Newton discovered it for us: In the 100-pound object there is ten times as much matter to be set into motion as in the 10-pound object; hence it takes ten times as much force to bring about the same rate of increase in speed.

According to a traditional story, Sir Isaac Newton one day, as he watched an apple fall to the ground in his garden, thought about the problem of gravity. He wondered how far out from the earth the pull of gravity extended. Did the same force that caused the apple to fall reach all the way to the moon and so control its revolution around the earth? Might there not be a similar force coming from the sun which caused the planets to revolve about it? In order to answer these questions, Newton plunged into a series of experiments and mathematical calculations that extended over a period of many years. The result was the discovery and statement of the *law of universal gravitation: Every particle of matter in the universe attracts every other particle with a force that varies directly as the product of their masses and inversely as the square of the distance between their centers.*

This statement of the law needs further explanation to make clear its meanings. In the first place, it speaks of *universal* gravitation because such a force exists between all bodies in the planetary system—and probably throughout the universe—as well as between the earth and objects on the earth. Then, too, gravitational force is *mutual* between objects. When a man without a parachute falls out of an airplane, the earth pulls on him and he pulls on the earth with the same force. He falls down to meet the earth, and the earth is drawn up to meet him; but the earth, being so much heavier, moves ever so slightly.

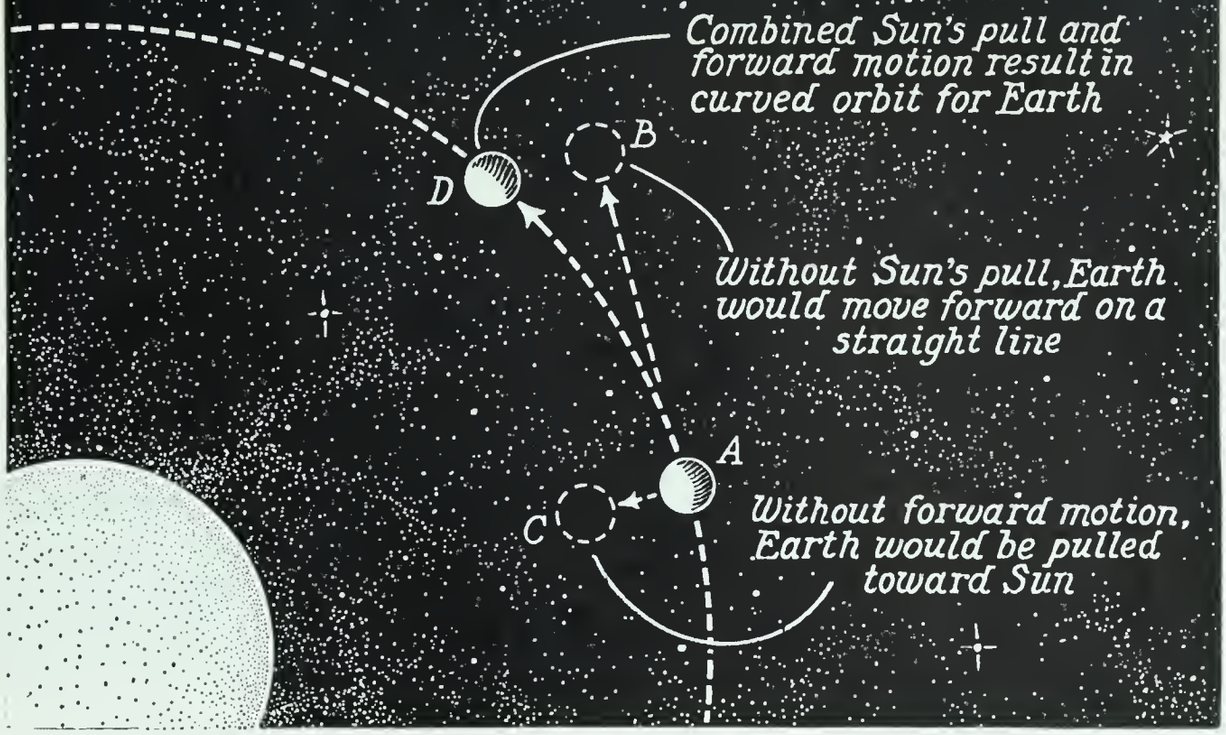
Now let us consider what happens to the gravitational force between two bodies when they are moved farther and farther apart. Suppose the earth exerts a pull of 3,600 pounds on a certain object at its surface. Since the earth's *center of gravity* is 4,000 miles down from its surface, in order to double the distance between the object and the earth's center of gravity, we will move the object 4,000 miles out into space. If we could now attach a

spring scale to the object and measure the pull of the earth on it, we would find it to be one-fourth as much as before $\left(\frac{1}{2^2}\right)$; the scale would read 900 pounds. Remember that Newton found gravitational force to decrease as the distance squared increases. Taking the object out another 4,000 miles would increase the original distance to three times, and the pull of the earth on it would then be only one-ninth as great $\left(\frac{1}{3^2}\right)$; the spring scale would read 400 pounds. This explains why objects weigh more at sea level than on a high mountain and more at the poles than at the equator. What would be the pull of the earth on our object if it were taken as far away from the earth as the moon? The moon's distance is 240,000 miles, which is sixty times the original distance (240,000 ÷ 4,000). Consequently, the pull of the earth would be decreased to one thirty-six-hundredth $\left(\frac{1}{60^2}\right)$ and would amount to only 1 pound.

Now let us consider how gravitational forces and inertia operate to keep the heavenly bodies in their courses. The earth exerts a pull on the moon that causes it to fall toward the earth just as the apple fell in Newton's garden. Starting from rest, the moon and the earth would soon come together. But the moon does not fall to the earth because it is moving forward so swiftly all the time that the earth's pull succeeds only in changing its path from a straight line to a curved one.

Study the diagram on page 217. With the earth in motion at point A, its inertia should carry it in a straight line to position B during a certain time interval. With the earth at rest in position A, the sun's pull should cause it to fall to position C during the same time. Since the earth is in motion and since the sun's pull operates at the same time, the result is that the earth's path continually curves and the earth moves to position D.

In one second the earth goes forward about 19 miles in a direction at right angles to the line of the sun's attractive force. During this same time it falls less than one-eighth of an inch toward the sun. This very slight deviation from a straight line every second during the year is sufficient to cause the earth to revolve about the sun in a nearly circular orbit. In similar fashion, all the other planets revolve about the sun as the combined result of inertia and gravitational attraction.

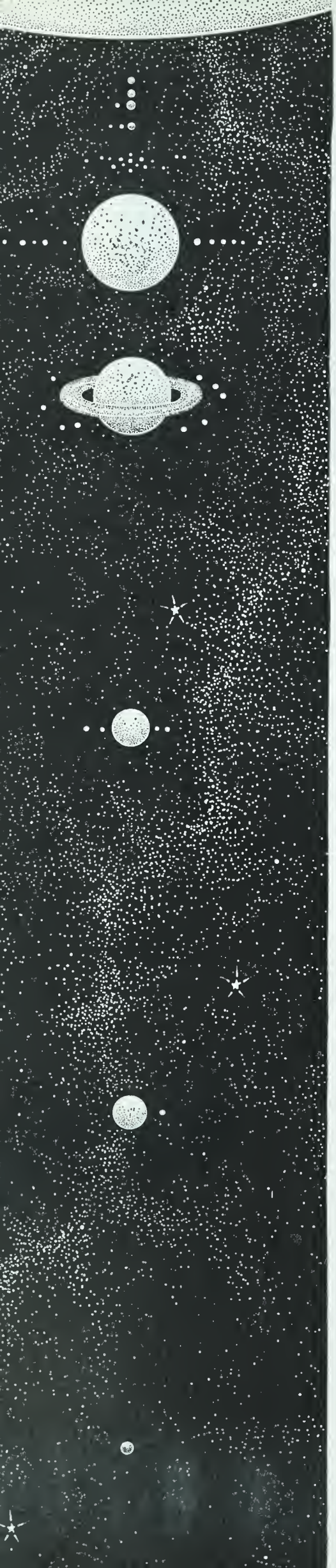


• THE SUN'S FAMILY

At the time of Copernicus, seven "wanderers of the sky" were known. Since that time, the known membership of the sun's family has greatly increased. Three new planets—Uranus, Neptune, and Pluto—have been discovered, making a total of nine principal planets known to revolve around the sun. Careful investigation has shown that other planets like the earth have moons which accompany them as they wheel around the sun. In fact, our moon is only one of twenty-eight such celestial bodies. In addition to planets and moons, the sun's family as we know it today includes thousands of asteroids, or minor planets, dozens of comets, and several meteor swarms, all of which journey about the sun in definite orbits. This entire assemblage of celestial bodies, the sun included, constitutes what is known as *the solar system.*

Nine major planets revolve around the sun. The table below contains interesting information about these planets. Pluto has been so recently discovered that some information concerning it

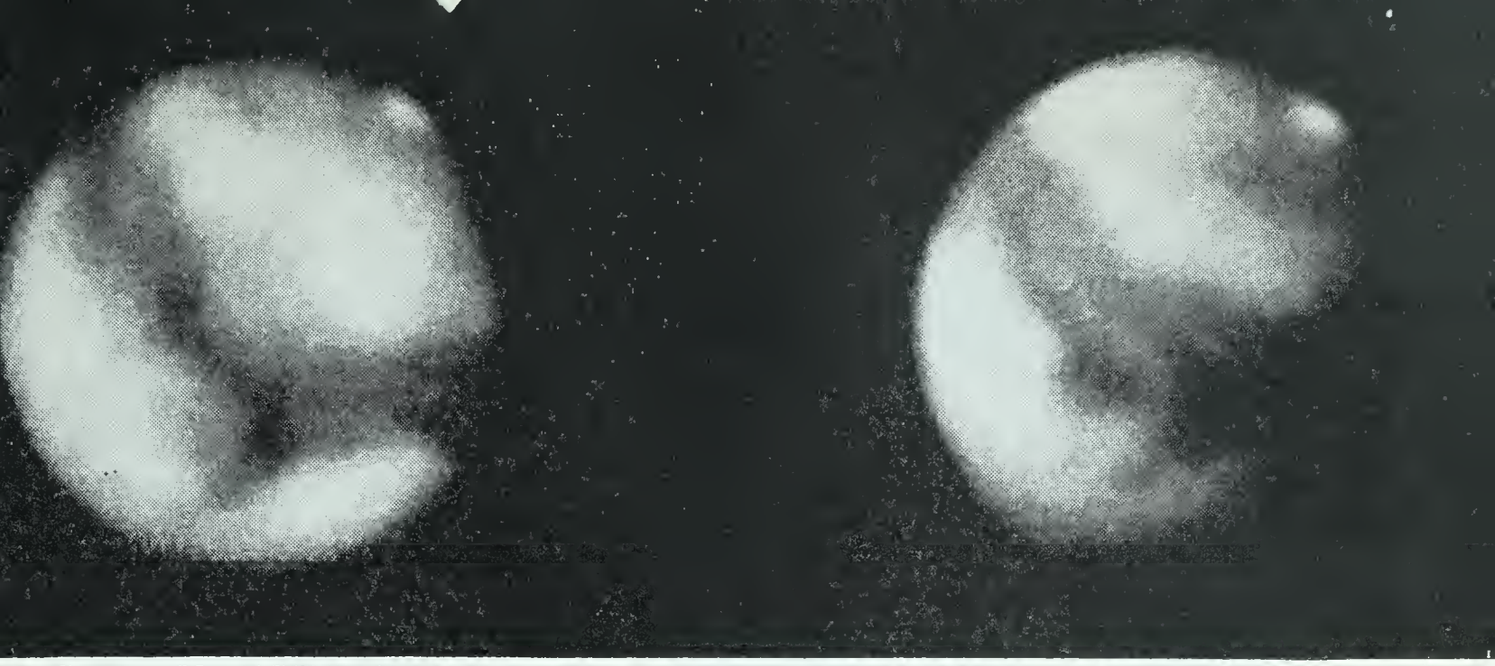
Name	Average distance from sun in millions of miles	Period of revolution about sun	Period of rotation	Equatorial diameter in miles	Density compared to water	Times as heavy as the earth	Number of known moons
Mercury	35.9	88 days	88 days	3,100	3.8	0.04	0
Venus	67.2	225 days	.....	7,700	4.9	0.81	0
Earth	92.9	365.25 days	24 hrs.	7,927	5.5	1.00	1
Mars	141.5	687 days	24 hrs. 37 m.	4,215	4.0	0.11	2
Jupiter	483.2	12 years	9 hrs. 50 m.	88,640	1.3	317.	11
Saturn	885.9	29.5 years	10 hrs. 38 m.	74,100	0.7	95.	9
Uranus	1782.0	84 years	10 hrs. 48 m.	32,000	1.3	15.	4
Neptune	2793.0	165 years	15 hrs. 48 m.	31,000	1.6	17.	1
Pluto	3670.0	248 years	.....	.....	.....	.....	0
Sun	.....	.....	.....	864,100	1.41	331,950	....
Moon	.....	.....	.....	2,160	3.33	0.012	....



is not known with enough certainty to be included. The sun and moon are also given for the purpose of comparing certain items.

Mercury, the smallest planet in the solar system, is about one and a half times the size of our moon. It is thought to rotate once on its axis in the same time that it takes to revolve once around the sun—namely, eighty-eight of our days. If this is so, then a day and a year are the same length on this planet, and Mercury keeps the same face always toward the sun. Mercury is so close to the sun that the rocks on its sunny side are hot enough to melt lead, bismuth, tin, sulfur, and other elements that melt at around 350° C. or below, while on the other side, it is very cold and eternal darkness prevails. Mercury is so small that its gravitation cannot retain an atmosphere and there seems to be no water on the planet. We conclude that Mercury is a waterless, airless, lifeless world.

Venus has often been called "the twin sister of the earth." This is because of its similarity in size, weight, and density and also because it is the planet nearest the earth, sometimes being only about twenty-six million miles away. Venus is always enshrouded in dense clouds, and for this reason



Courtesy Mount Wilson Observatory

Is there life on Mars? What kind of people could live there? These questions about Mars have long made it the most interesting of the planets.

astronomers have not been able to see through to the surface of it—the actual planet itself is still a mystery. At the present time, no one can say with certainty whether there is life on Venus. There is much carbon dioxide in the atmosphere, but oxygen is either absent or is present only in very small amounts. Since plants give off oxygen and animal life as we know it requires considerable oxygen, life on Venus seems improbable.

Both Mercury and Venus revolve inside of the earth's orbit, and for this reason they are especially interesting to observers of the sky. They seem to swing back and forth past the sun's place, appearing at times as bright "evening stars" in the west after sunset and again at other times as brilliant "morning stars" that rise in the east ahead of the sun. Relatively few people have glimpsed Mercury because it is so close to the sun, but almost everyone has noticed Venus. It is the third brightest object in our heavens, being exceeded in brilliance only by the sun and moon, and can even be seen on occasions during daylight hours shining like a tiny star. Mercury and Venus both display all the phases of the moon.

Mars is known as the red planet. The light reflected from it is distinctly reddish in color. This suggests the probability that the surface of this planet, like much of the earth, consists of rocks and soil colored red by iron oxide. Gray-green patches on its surface suggest vegetation, but for the most part Mars is believed to be a desert and to have no large bodies of water. Whatever moisture the planet has seems to be concentrated at the poles, where large, white areas form during the Martian winter and almost disappear in summer. They are thought to be either polar caps of snow and ice or large fog areas overlying the polar regions. Since water is so scarce on Mars, its atmosphere is clear enough for astronomers to



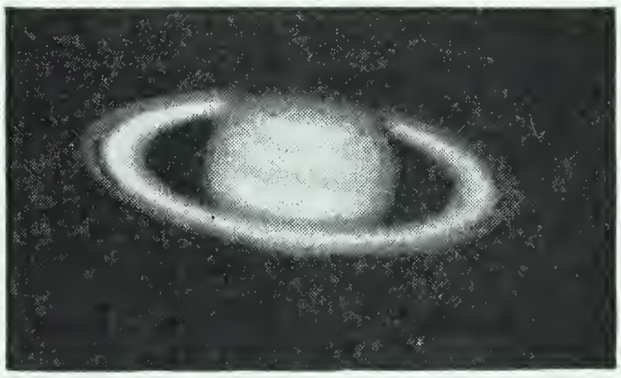
Courtesy Mount Wilson Observatory

Jupiter, the largest planet, is circled with belts of clouds. One of its eleven moons and the shadow of a moon can be seen in the picture.

see through to the surface of the planet. One of the most striking features to be seen is a network of markings, which were named "canals" by their discoverer. It was suggested at first that these streaks might actually be artificial waterways constructed by intelligent beings to conduct water from the melting polar ice caps to arid parts of the planet. Very few astronomers, if any, believe this hypothesis today. Nevertheless, a question as to the possibility of life on Mars still persists. Let us consider the evidence pro and con, keeping in mind that by "life" we mean life as we know it here on earth.

The moisture content of the Martian atmosphere is perhaps only 5 per cent of that of ours, while oxygen is probably not nearly so plentiful as at the top of Mount Everest. Both conditions would be severe handicaps to life. During the change of seasons on Mars, certain markings become greener and more pronounced during the advance of summer; then, with the onset of fall, they fade and become brownish. It can easily be imagined that these color changes indicate the presence of plant life. Mars is so much farther from the sun than the earth is that it receives less than half as much heat and light. Nevertheless, its noonday temperature near its equator has been found to run from 32° F. to 80° F., a range suitable for some forms of life. If life does exist on Mars, it must be a kind adapted to all of the afore-mentioned conditions and hence quite different from the type of life on earth. It may be that Mars now represents a stage in the earth's history which was passed through millions of years ago—or, perhaps, a stage which the earth will experience millions of years hence. Since the evidence is not entirely conclusive, it seems best to suspend final judgment concerning the existence of life on Mars.

If all the planets except Jupiter were combined into one, the resulting mass would not weigh as much as Jupiter, the Giant. This great planet attracts attention because of its brightness—



Courtesy Mount Wilson Observatory

What is the origin and significance of Saturn's rings? The answer to this question might furnish a clue to the way in which our solar system was formed.

among the starlike bodies in the sky, only Venus and occasionally Mars exceed it in brilliance. In 1610, Galileo viewed Jupiter through his telescope and discovered its four largest moons; since that time, better telescopes have revealed seven additional ones. Jupiter is so thickly covered with clouds that no one has ever seen the face of the great solid planet that is believed to be underneath. The clouds on Jupiter consist of vapors of methane and ammonia, rather than water. This, together with the fact that the temperature is about 200° below zero Fahrenheit, seems to rule out the possibility of life on the planet.

When viewed through a telescope, Saturn is a most unique and spectacular object because of its famous rings. The rings are not solid but are composed of swarms of small revolving particles thought to be the remains of a moon that exploded; thus each particle can be thought of as a tiny "moonlet." There are times when the rings are edgewise to the earth, while at other times either their northern or southern side is tilted toward us. When the rings are edgewise, they cannot be seen as such, except through a moderately large telescope, because they are so thin. They were nearly edgewise when first observed in 1610 by Galileo through his small telescope. He saw only two bright spots on opposite sides of the planet and therefore described Saturn as "the planet with wings."

If the rings were removed from Saturn, it would closely resemble Jupiter, both as to size and prevailing conditions. Its atmosphere contains methane and ammonia. It is a cold, cloud-covered world. A year on Saturn is more than twenty-nine of our years; a day is only about ten hours long. Saturn is the most distant of the bright planets, the most remote one known to the ancients, and the most remote planet that can be seen without the aid of a telescope.

The most recently discovered members of the sun's family of planets are Uranus, Neptune, and Pluto. These planets are very cold. Uranus and Neptune are covered by dense clouds. As yet,

little is known about Pluto. The most interesting facts about these planets relate to their discovery.

While exploring the sky with his telescope in 1781, Sir William Herschel, an Englishman, chanced to see a previously unreported object. He reported it to The Royal Society as a comet. Further observation of its motion among the stars revealed that it was really another "wanderer" or planet. It was named Uranus. An orbit was calculated for Uranus, and for a while it followed the predictions of astronomers very nicely. But as time went on, Uranus began to deviate from its predicted orbit. This behavior puzzled and worried the astronomers, for they felt sure they couldn't be wrong—they had taken into account the influence on Uranus of all the other known planets and had checked and rechecked their calculations and their observations many times. In 1846, Urbain Leverrier in France got the idea that there must be a disturbing influence somewhere which was as yet unknown. He began to calculate where it ought to be. Leverrier wrote to the astronomer, Johann Galle, at the Berlin Observatory and asked him to verify these calculations by observations. Galle pointed his telescope as directed, and sure enough—he soon detected a new starlike object which proved to be the source of the disturbing force. Thus the planet Neptune was added to the known membership of the sun's family.

After Neptune had been discovered and a new orbit was calculated for Uranus, the latter began to deviate again. In 1915, the American astronomer, Percival Lowell, predicted another planet beyond Neptune, calculated its orbit, and predicted how Uranus should behave in years to come if such a planet were there. During the succeeding years, Uranus followed the predictions of Lowell, but the new planet, Pluto, was not located and identified until 1930.

Our universe is full of seeming mysteries, but undoubtedly there is a rational explanation for every one. The scientist is curious about his environment, but he does not believe in superstitions or signs of good or bad luck. He tries to find reasonable explanations as to how and why things happen. He makes careful and exact observations to discover reliable facts on which to base these explanations and believes that the search for facts must be continued until an adequate explanation can be given for every perplexing occurrence. He believes that judgment must be suspended until sufficient facts have been accumulated. The discovery of Neptune and of Pluto demonstrated the power of scientific

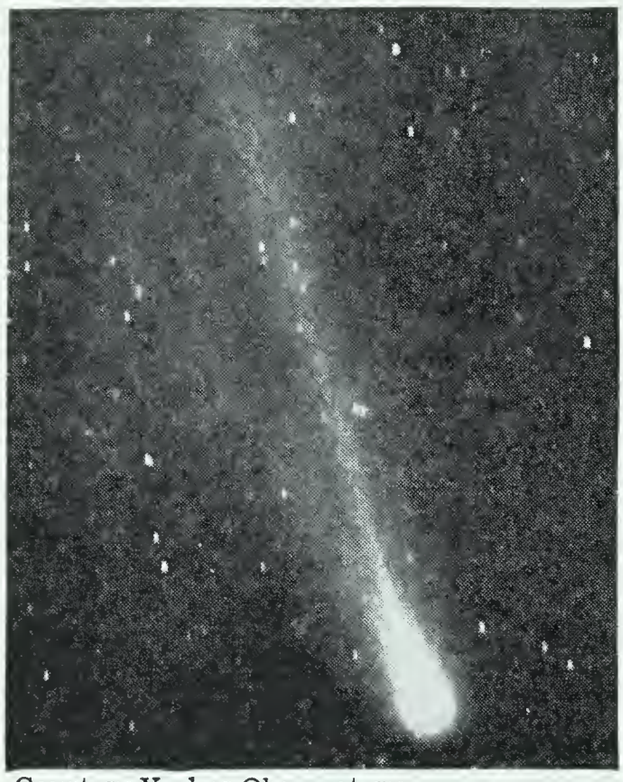
reasoning and investigation and forcefully illustrated the idea that our universe is law-abiding—that for every effect there is a cause.

Are there other planets beyond Pluto? This is a logical question in view of the circumstances leading to the discovery of Neptune and Pluto, but many years may pass before it is answered. Uranus takes 84 years to go once around the sun, Neptune 165 years, and Pluto 248 years. So you can see that it may be a long time before astronomers can tell whether Neptune and Pluto are following the orbits they should have if there are no additional planets beyond Pluto. If they fail to follow these paths, there may be additional worlds beyond Pluto still to be revealed.

Asteroids, comets, and meteors also belong to the solar system. Asteroids are really tiny planets that revolve around the sun, chiefly in the zone between the orbits of Mars and Jupiter. The known ones range in size from about one-third of a mile to 480 miles in diameter. Since 1801, about 1,400 asteroids have been discovered and named; altogether they would not make even a fair-sized planet. Because of the highly elliptical orbits which a few of them have, there are several asteroids that can approach to within 15,000,000 miles of the earth. The nearest approach yet recorded occurred in October, 1937, when the tiny asteroid, Hermes, came within 400,000 miles of the earth. It is interesting to speculate as to what would happen if one of these asteroids came near enough to be captured by the earth's gravitational pull. Would it go spinning around us as a tiny moon, or would it crash down to earth? There seems to be no likelihood that this will happen; there is more danger from meteors and comets, but even in the case of these there are no verified records of any human

A comet goes away from the sun with its tail ahead and its head behind.





Courtesy Yerkes Observatory

This comet was photographed with a twenty-four inch reflector at an exposure time of six minutes. In which direction was the comet traveling?

being ever having been struck or killed by a falling meteor. In 1910, the earth passed through the tail of Halley's comet with no noticeable or harmful effects. Insurance against the risk of damage being done by falling asteroids, meteors, or comets would be very cheap indeed!

Of all the members of the solar system, comets excite the imagination most strongly. From remote times, comets have been regarded with fear and superstition by many people; the approach of a comet has often been looked upon as a sign of bad luck or strange happenings to follow. But times have changed. Today, people who understand the sky look forward to the approach of a comet, because it is an astronomical treat to see one. A comet consists essentially of two parts: a head, which may be a million or more miles in diameter, and a tail, which may stretch out into space anywhere from ten million to one hundred million miles. In spite of their great size, however, comets contain very little matter. The tail is thought to consist chiefly of glowing gases, while the head of a comet is probably composed of an enormous swarm of very tiny particles of matter widely spaced. The tail of a comet is composed of such extremely light-weight stuff that the pressure of sunlight pushes it away in a direction opposite to the sun. Consequently a comet goes away from the sun with its tail ahead and its head behind. The orbits of comets are so elongated that many comets do not return for from fifty to seventy-five years. Comets are the only members of our solar system, excepting the sun, that are self-luminous.

The streaks of "shooting stars" really are the trails of meteors that have fallen into the earth's atmosphere. The earth is bombarded constantly by hordes of these small stony or metallic messengers from outer space—perhaps a billion a day. The trails of

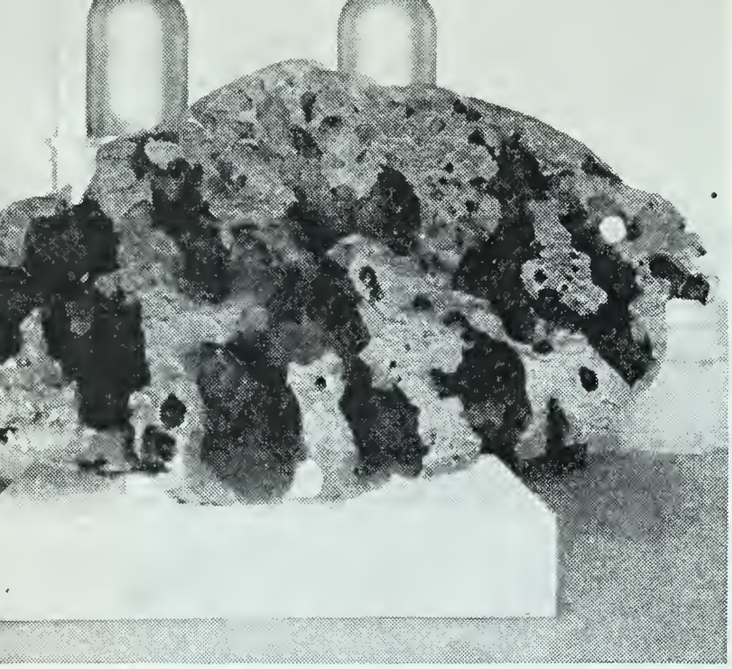
light result from the burning of the meteors as they become intensely heated by the friction encountered in rushing through the upper air at speeds of 7 to 49 miles a second. Most meteors burn to fine ashes and gases by the time they come within sixty miles of the earth, but a few meteors are large enough to reach the earth itself without burning up completely; their remains are called meteorites. Meteorites are the only heavenly bodies except the earth that man can actually touch.

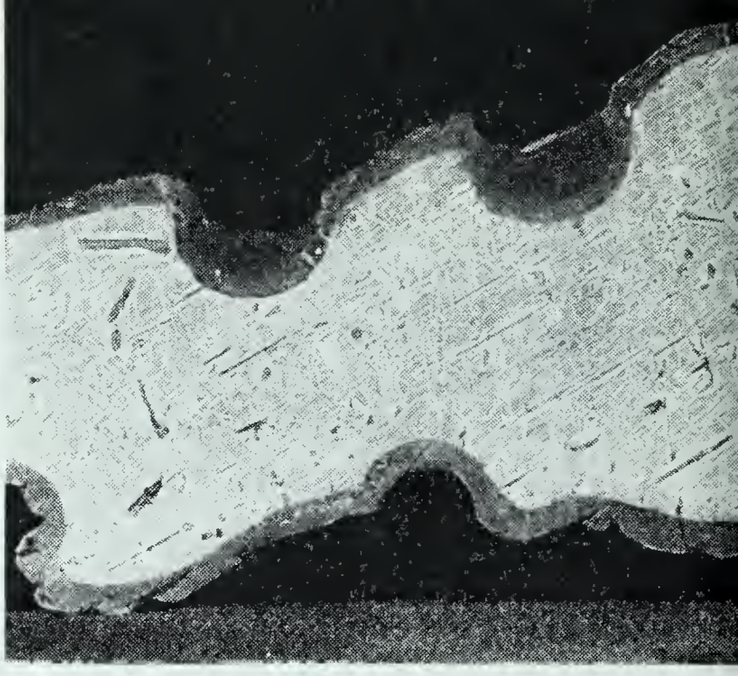
When exceptionally large meteors strike the earth, they produce meteor craters and may do considerable damage. The largest known crater is located in Arizona. It is a huge bowl-shaped depression almost a mile across and nearly 600 feet deep and is surrounded by a rim which rises about 150 feet above the level of the plains around. There seems to be no doubt as to the source of Meteor Crater. Scientists are agreed that either a huge meteorite or a small comet—the head of which was composed of meteoric material—struck at this point many thousands of years ago. The force of the crash and the heat generated by the impact caused rock for hundreds of feet below the surface to be blasted out as if by a supercharge of high explosive. The pulverized, and sometimes molten, rock debris was scattered over a wide territory, and the rim of the crater is composed of this same material. Many small meteorites have been found in the vicinity, but it is believed that the main mass of meteoric material lies buried under the south rim at a considerable depth. This Arizona crater may contain a million or more tons of iron and nickel, the two metals com-

Below is the photographic record of the flight of a meteor.

Courtesy American Museum of Natural History







Courtesy American Museum of Natural History

Left: This meteorite, unearthed at Willamette, Oregon, is the largest ever found in the United States, weighing sixteen tons. What hypothesis would you formulate to explain the extensive irregularities commonly found on one side of a meteorite?
Right: A cross section of a meteorite exposes the internal crystalline structure.

monly found in metallic meteorites. The lure of this possibility has led to many attempts to locate and recover this meteoric mineral wealth, which if valued at only one cent a pound would be worth $20,000,000.

Where do meteors come from? It is not known for certain whether all meteors belong to the sun's family or whether a considerable portion comes from outer space beyond the solar system. Perhaps meteors are the leftover material out of which the solar system was formed. Many astronomers think they may be the remains of disintegrated comets; at any rate, certain comets have disappeared, and when the earth passes through their former orbits, brilliant showers of meteors are observed.

• OUR NEAREST NEIGHBOR

How would you like to go exploring the moon? The journey would be a fascinating, thrilling experience you would never forget, if you could only get there and back safely. Such a trip, while not possible in fact, can be made in the imagination. Let's go!

Our space ship is a streamlined super-rocket, capable of a speed of 30,000 miles an hour. As we speed on through space towards our objective 240,000 miles away, we see the earth receding behind us; entire continents can now be seen in outline, and what we see leaves no room for doubt that the earth is really a spinning

Courtesy American Museum of Natural History



ball. But what is that strange feeling of lightness that comes over us? We find ourselves able to walk up the walls of our ship and across the ceiling just as easily as on the floor. Of course—that is because we are away from the earth; we are out in space now where there is no "up" or "down." These are earthly ideas that operate only when we are on or very near to a huge body like the earth; when we get to the moon and land, then we can use them again.

One hour to go—the moon is only 30,000 miles away. Glance out of the window for another look at the celestial scenery. All around, the sky is black as midnight, and the stars are shining brightly; but they don't twinkle here as they did up on the earth—why is that? And look! The sun is shining with dazzling brilliance. Never before have we seen the stars come out while the sun is shining. Maybe they are different stars than we ever saw before. No, they must be the same ones, for there is the Big Dipper, Cassiopeia, Orion, and other familiar constellations we see from the earth. But where is the earth? Nowhere can it be seen. Probably it is a "new earth" and invisible to us now for the same reason that back home we cannot see a "new moon"; perhaps in a day or so we will see the crescent of the earth as it begins to go through its phases.

Look below us! What a weird, wonderful sight the lunar landscape presents! We see huge, rugged mountains cleft by yawning chasms and deep valleys. There are numerous craters like Meteor Crater in Arizona back home, but these are even larger—some must be 150 miles across, and their walls rise 20,000 feet above the plains. Everything is dazzling white or coal-black depending upon the distribution of sunlight and the shadows cast. Let us select a small crater and land on its smooth floor, where we will camp for a while.

Before we leave the hermetically sealed ship to go exploring, we must put on special suits in which a pressure equal to the earth's atmospheric pressure can be maintained and which also carry a supply of compressed air for us to breathe—for there is no atmosphere around the moon. As we step outside what a strange land greets us! (It looks like the drawing on page 227.) There is no water anywhere, so it is fortunate we brought along an ample supply. Everything is rock; there is no soil, no vegetation or other life. The moon is a dead world—a barren, lifeless desert. Since there is no water, it can never rain on the moon. And, desert is the right name, for with the sun overhead the

temperature is 250° Fahrenheit! With no air to check their flight, meteors come crashing against the moon's surface. Since they do not burn, they retain their full size on the way down. But no sounds are heard as they crash; in fact, no sounds whatever break the awful stillness—we cannot hear each other speak even when shouting with all our might, and we must communicate by specially designed radio equipment. What a difference a little air makes! And everything is so light! We can easily lift objects that would weigh 150 pounds or more upon the earth. We find it a simple matter to jump over rocks 20 feet high that lie in our path; it's just as easy as jumping over a 3-foot stone back home. This is fun.

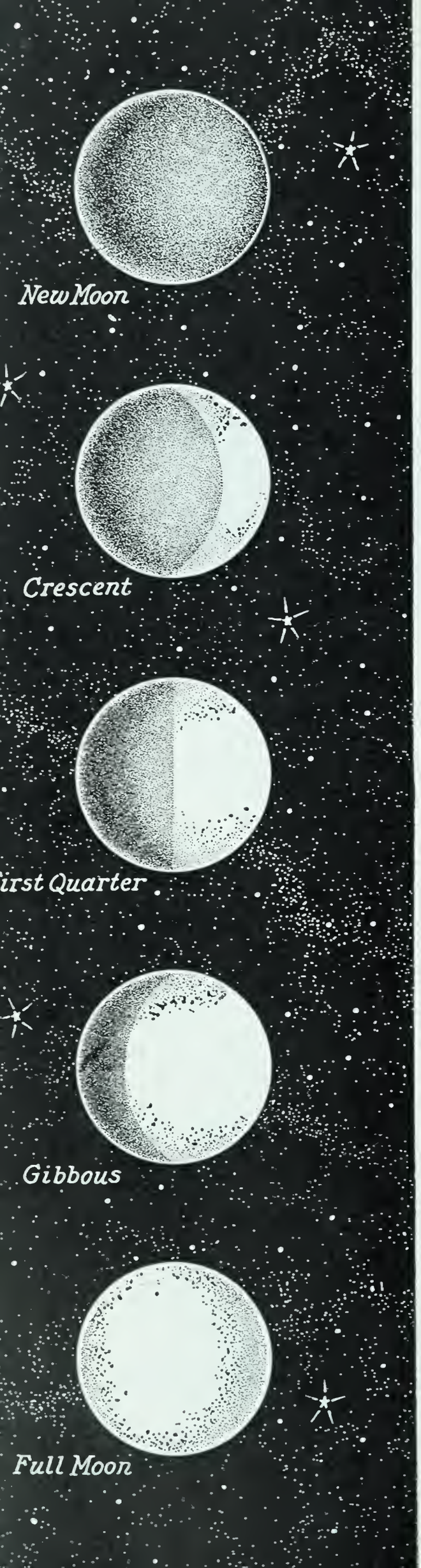


Courtesy American Museum of Natural History

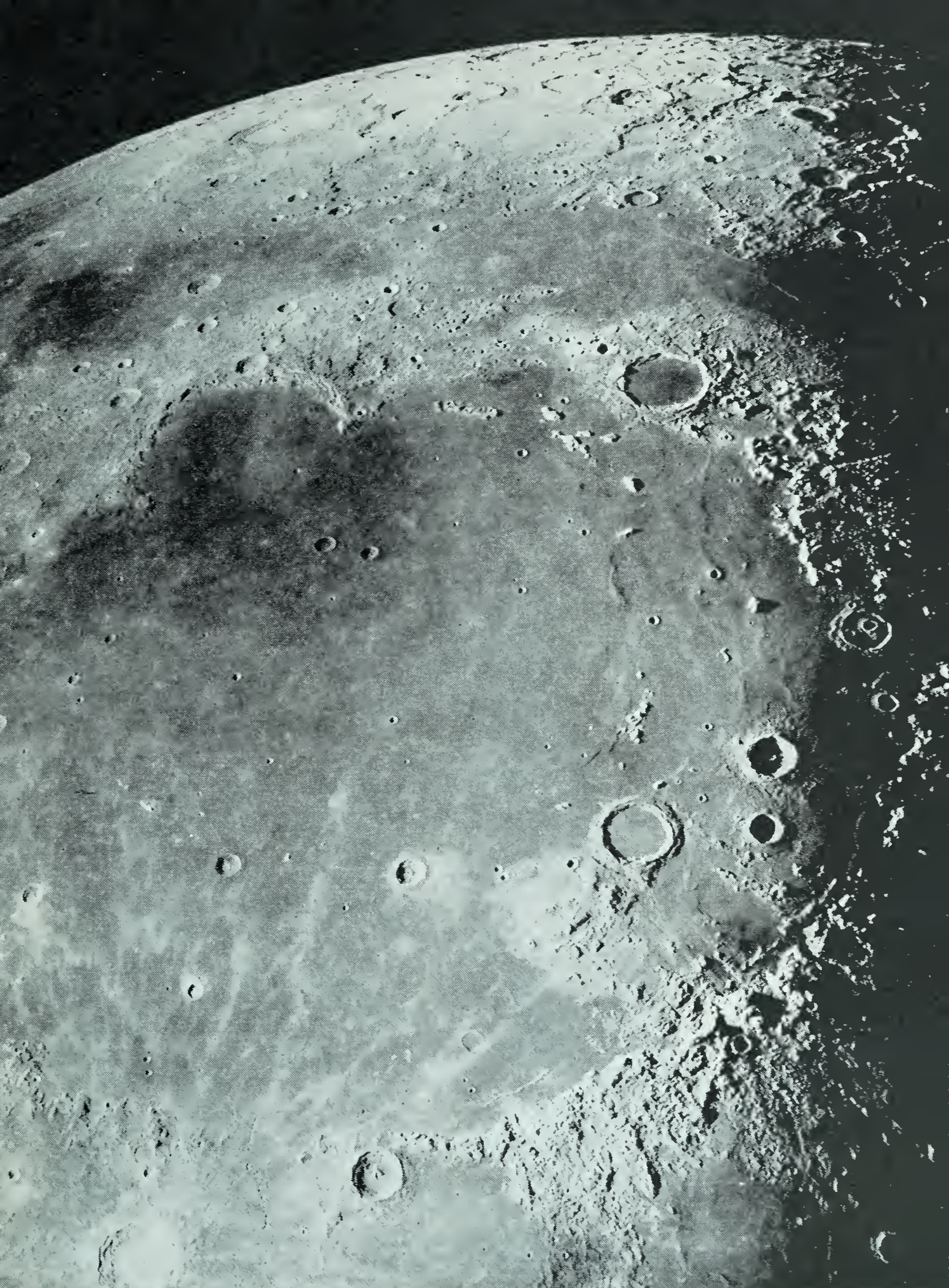
You would see something like this if you could pay a visit to the moon. An artist depicts the rugged lunar landscape lighted at night by the moon's nearest neighbor—the earth.

Four weeks on the moon have satisfied our curiosities and have convinced us that "there is no place like home." We have no further desire to prolong our stay; living through a day and a night on the moon is enough. It was high noon when we landed, and the sun was directly overhead. Slowly it passed westward and, one week later, suddenly dropped below the horizon. Instantly, everything was in utter darkness; there was not even a semblance of twilight. And the temperature began to drop rapidly; in a very short while, it was more than 100° below zero, Fahrenheit. For two weeks, we endured the arctic night. Then, as suddenly as it had previously disappeared, the sun rose above the eastern horizon and it was daylight again. Once more, there was no preliminary twilight, and in a short while the temperature had climbed back to 250° above zero. Slowly climbing and climbing, the sun reached the zenith today—one earth-week after rising. During our stay on the moon, we have had the experience of watching the earth go through all the phases. And now it is time to return home.

Each time the moon comes up over the horizon, it does so a little



later than it did when it rose the time before. Hence, we conclude, the moon revolves eastward around the earth. The changing shapes displayed by the moon during its journey around the earth are called phases; they result from the fact that the moon, like a planet, is a body which shines only by reflected sunlight. Therefore, only the half of the moon turned toward the sun is illuminated, while the opposite hemisphere is in total darkness. As the moon goes eastward around the earth, varying amounts of the sunlit half of the moon come into view and we see the different phases. When the moon is on the same side of the earth as the sun, we cannot see it at all and we have a "new moon." About two or three evenings later, a thin "crescent moon" can be seen in the west after sunset; the horns of the crescent grow thicker and thicker resulting in a semicircular moon described as "first quarter." The next phase is "gibbous," in which the moon becomes bulging and lopsided as it continues on its eastward journey. The round "full" moon is in the east, directly opposite the sun, and all of the sunlit side is visible to us then. As the journey continues, the same phases are repeated in reverse order: gib-



Courtesy Mount Wilson Observatory

A part of the moon's surface as seen in a one hundred-inch reflecting telescope. The craters range up to about fifty miles in diameter and the mountains to about five miles in height, comparatively much higher than any found on earth.

bous, last quarter, crescent, and once again a new moon. When the moon is a thin crescent, the rest of the disk can usually be seen faintly lighted by "earth shine." Earth shine is caused by the reflection of sunlight from the earth to the moon. Since at such times the crescent seems to encircle the dimly lighted part of the disk, this condition has been described as "the old moon in the new moon's arms."

The period of the moon's journey once around the earth differs from the period from new moon to new moon by a little more than two days. If the earth were stationary, the moon would appear to go once around us in about 27⅓ days; which it really does in fact. But the average time from new moon to new moon is about 29½ days. The cause of the difference is the earth's revolution around the sun. While the moon is going around the earth, the earth is going forward around the sun. Consequently, the moon must go a little farther than once around the earth in order to come once again between the earth and sun.

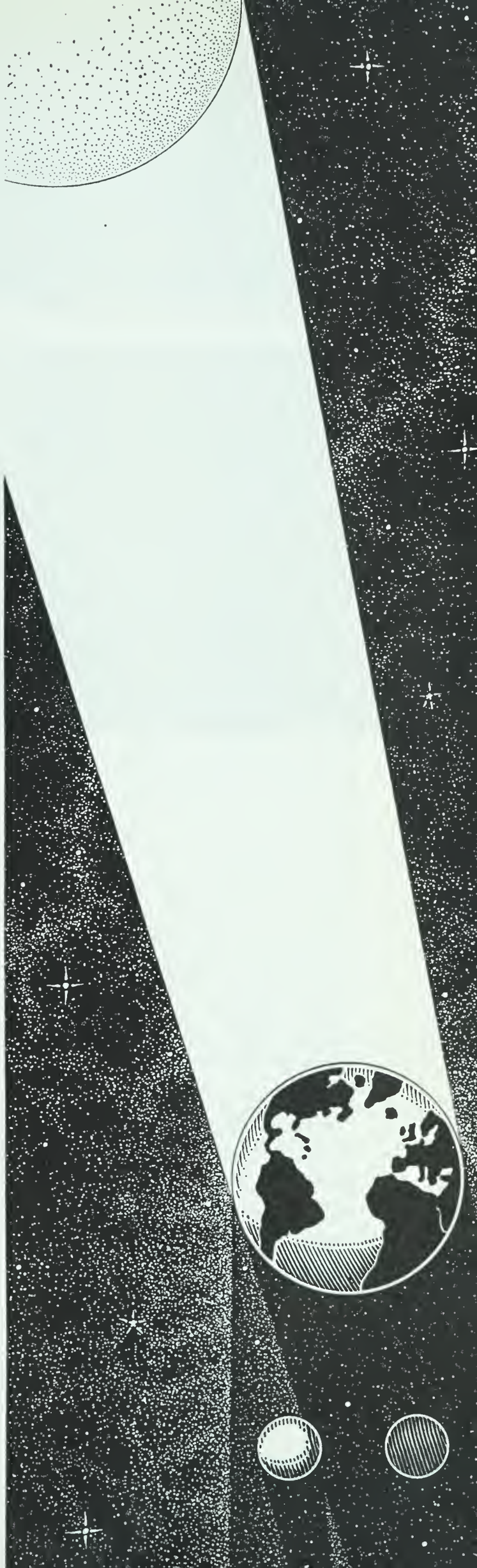
The path of the moon around the sky is tilted with respect to the orbit of the earth. If this were not so, at every new moon, the moon would be directly between the earth and sun, and its shadow would be cast on the earth. People within the shadow would see the sun blotted out and there would be an eclipse of the sun. Likewise, at each full moon, the moon would have to pass through the shadow cast by the earth and there would be a total eclipse of the moon. But since the moon's path is tilted, most of the time it passes either north or south of the direct line joining earth and sun; hence, eclipses occur infrequently.

The earth casts a cone-shaped shadow that extends about 850,000 miles into space and from which all direct rays of light from the sun are cut off by the earth itself. When the full moon plunges into this shadow, a total eclipse occurs. As the eclipse proceeds, a shadow slowly spreads over the moon. The edge of this shadow is always part of a circle, and this fact was regarded by many of the ancients as adequate proof that the earth is a globe. When the moon is completely within the shadow, it glows with an eerie, copper-colored light. The effect is caused by the earth's atmosphere bending the sun's light in such a way that its red rays strike the moon, similar to the sunset effects commonly observed. If the moon passes centrally through the earth's shadow, the total eclipse can last as long as one hour and forty minutes. Eclipses that are partial throughout their duration result when the moon passes too far from the center of the shadow to be enveloped com-

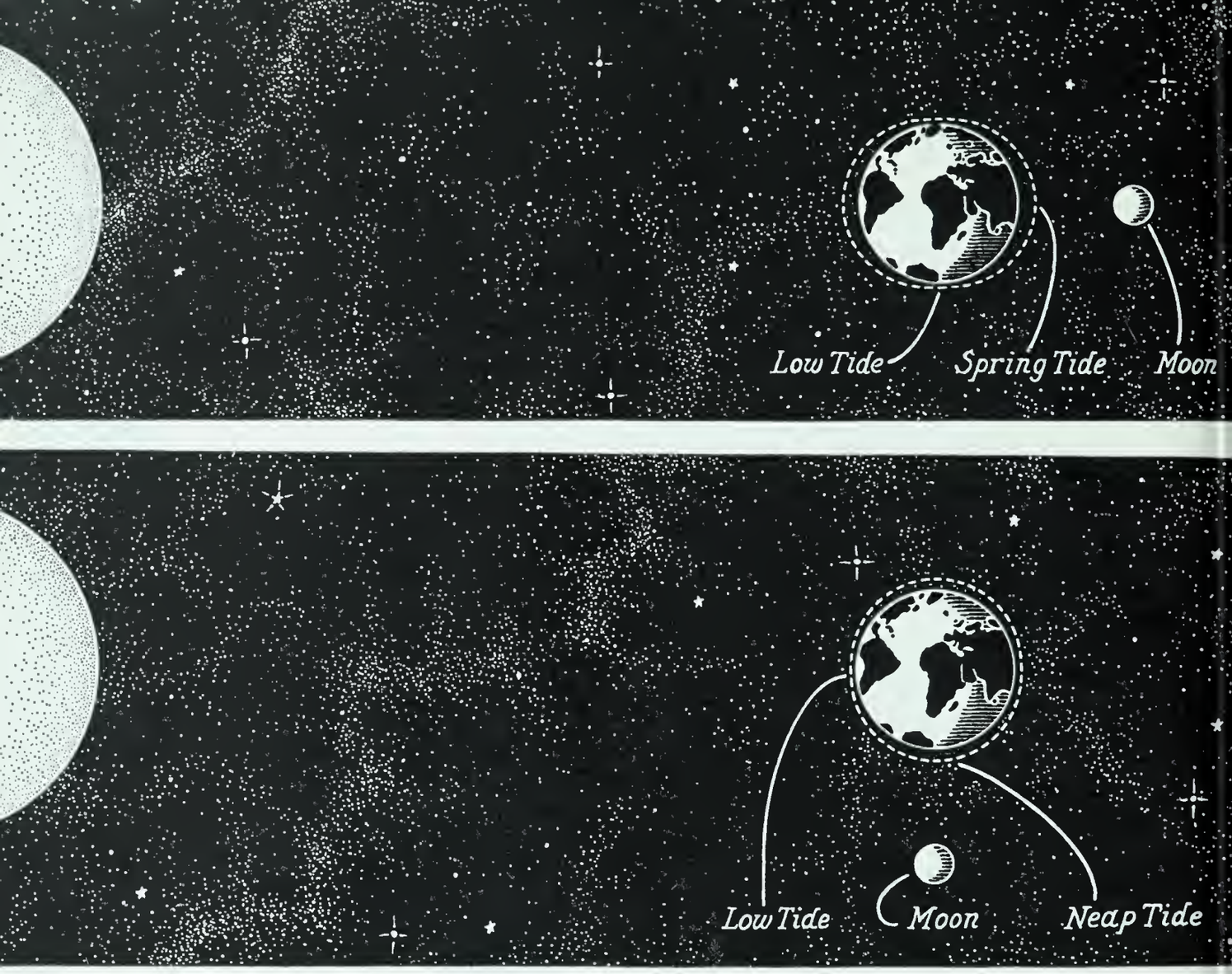
pletely. Lunar eclipses can be seen from any place on earth where the moon is in view; this would include the half of the earth turned toward the moon, plus the added part that turns into view during the eclipse.

As the moon goes once around the earth, it also turns once on its axis. This is inferred from the fact that the same side of the moon is always turned toward the earth. No human eye has ever glimpsed the other side of the moon, and, if there were people there, they would never see the earth in their sky. However, since the moon wanders north and south during its revolution, as well as for other reasons, astronomers have been able to see 59 per cent of the moon's surface.

Have you ever stood along the shore by the ocean and watched the tide roll in? The thrill of this experience is climaxed with the realization that the moon is the chief cause. Reaching out through 240,000 miles of space, the moon's gravitation lifts up a huge bulge in the water. The earth turns under the bulge, and so the tide comes in toward the shore. The sun might also be expected to have a similar effect in producing tides, and it really does, but to a smaller degree because it is so far away



The moon in eclipse.



The gravitation of the sun may aid or interfere with the gravitation of the moon in producing the tides.

and the force of gravity decreases as the distance squared increases. The difference between high and low tides is greatest when the moon and the sun pull in nearly a straight line; that is, when they are on the same or on opposite sides of the earth. When their pulls are at right angles, the gravitational forces tend to neutralize each other, and the tides are neither so high nor so low as at other times. Twice every 29½ days, we experience both the very low tides, called neap tides, and the very high ones, called spring tides; there is no connection between the latter and the spring of the year.

From the preceding discussion of the moon and its motions, it is hard to understand how anyone living in the modern age could continue in a belief that the moon exerts a strange and powerful influence on people, weather, and crops. Surely no well-informed person believes that planting in the "light" or the "dark" of the moon will affect his potato crop; that a person's mental balance is determined by the moon; or other similar beliefs. Astronomy teaches us that there is a complete lack of evidence to support such fanciful and superstitious ideas; they, along with other astrological teachings, should be laid quietly, but completely, to rest.

• THE SUN ITSELF

The largest, brightest, and most conspicuous object in our sky is the sun. Blazing away day after day, it provides the light and heat without which life on earth would be impossible. In addition, almost every form of power used by man is transformed solar energy; this includes water power, heat from fuels and foods, the force of the winds, and practically all others that one may mention. The gravitational pull of the sun reaches out through millons of miles of space and holds the planets in their courses. The source of the sun's tremendous gravitational pull is its enormous size. It contains more than 99.8 per cent of all the matter in the solar system—enough material to make more than three hundred thousand bodies like our earth.

There are many questions to be asked regarding the sun: What is the nature of the sun itself? What is the source of the sun's energy? How much of the sun's energy output does the earth receive? What does the sun look like in total eclipse? How do the sun's radiations affect the earth and its inhabitants? As we discuss these questions, keep in mind that in studying the sun, we are also studying a star—for the sun is truly a star—the one nearest to earth and the only one near enough to permit close astronomical investigation.

Astronomers tell us that the sun is a sphere of incandescent gases. Its surface temperature is about 11,000° Fahrenheit, a temperature so high that iron, calcium, and other metals present are in the gaseous state. Great tongues of incandescent hydrogen, called solar prominences and glowing like the gas of a neon sign, leap thousands of miles above the sun's surface and out into space—but even though oxygen is present, there is no burning because it is too hot! Deep in the sun's interior, it is estimated that temperatures may run as high is thirty to forty million degrees Fahrenheit.

We naturally inquire as to the origin of the tremendous amounts of energy indicated by such temperatures. This question has perplexed men of science for decades, and several theories have been advanced as possible answers to the problem. Burning, chemical reactions, mechanical shrinkage, and radioactive disintegration have all been considered as possible sources of the sun's heat, but not one of them satisfactorily meets all requirements of the evidence. The story told by the rocks shows that the sun has fed heat



Courtesy Mount Wilson Observatory

The picture shows tongues of luminous hydrogen on the sun. Although both hydrogen and oxygen occur in this star, there is no burning—it is too hot!

to the earth at a practically constant rate for over a billion years. To supply this energy, any one of the sources suggested above would certainly have been exhausted long ago, and the sun would have cooled off. This is not the case. At the present time, the leading belief is that the sun is generating its enormous supply of energy at the expense of matter; that is, matter is being annihilated—matter is being changed into energy. How this happens has been calculated but has not been duplicated in laboratories by man—it is still the sun's secret. If the sun's mass is being changed into energy, it follows that the sun is doomed to extinction and life on the earth must come to an end—unless somewhere else matter is being remade. But even at the present rate at which the sun gives off energy, its present mass is sufficient to last for an estimated five or six trillion years!

The energy generated in the powerhouse of the sun is radiated in all directions with the speed of light. These radiations consist not only of visible light of all colors, but also of ultraviolet, infrared, and other waves which the eye cannot detect. At a distance of 93,000,000 miles, the earth intercepts less than one two-billionth of the total solar radiation, and much of this is filtered out by our atmosphere. In spite of these facts, however, an unbelievable amount of energy finally reaches the surface of the earth. Estimates of the Smithsonian Institution show that if the atmosphere

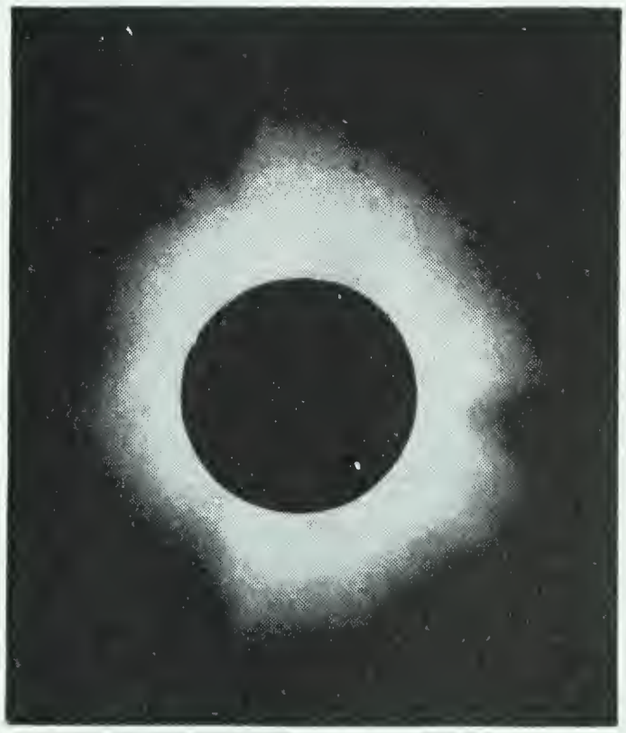
were cleared away, the earth would receive energy at a rate of more than 1.5 horsepower a square yard of surface area when the sun is directly overhead.

Cyclones occur on the sun, resulting in great whirlpools called sunspots. These disturbances have a dark appearance against the surface of the sun because their temperature is perhaps 3,600 Fahrenheit degrees cooler than the surrounding portions. Sunspots that can be seen at all vary in size from a few hundred to perhaps fifty thousand miles in diameter. One of the most interesting and important discoveries made regarding sunspots is that they are magnets. During periods of unusual sunspot activity, magnetic storms occur on the earth which seriously disrupt telegraphic and radio communication; "static" becomes very annoying. Also, the displays of northern lights are more frequent and more brilliant at these times. Just how the sunspots are related to these effects is not known, but investigation is underway and some interesting things have been discovered.

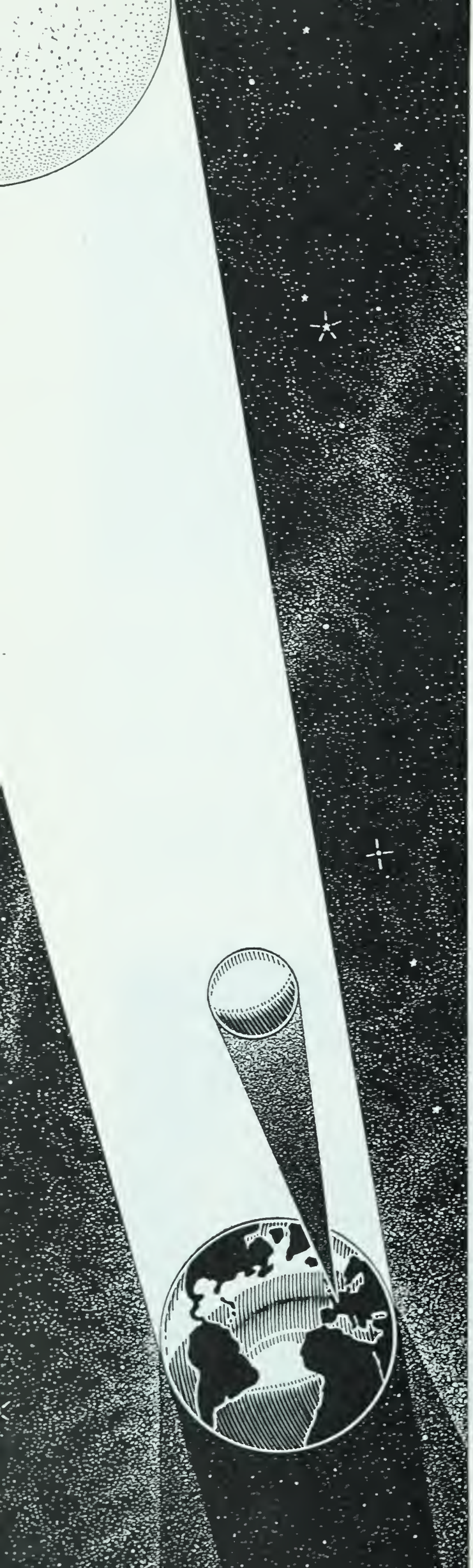
Sunspots unmistakably increase to a maximum and then decrease to a minimum in an average cycle of about eleven years; the year 1938 saw the maximum number of spots since early in 1928. We can expect another period of intense activity about 1950. Attempts have been made to connect sunspot cycles with weather conditions, the growth of trees, business cycles, and even the number of suicides. As yet, however, no conclusive evidence of a relationship has been found that is generally accepted by scientists.

In the total eclipse of the sun, the moon blots out the sun but gives us our only glimpse of the sun's corona, or gaseous envelope.

Courtesy Mount Wilson Observatory



A total eclipse of the sun is considered by many people to be the most magnificent heavenly display that man can witness. It is caused, of course, by the moon passing between the earth and sun in such a way that the moon's shadow sweeps across the earth. Under ideal conditions, the extreme



width of the shadow is 167 miles; anyone within the path of this shadow can see the eclipse as total, but elsewhere the eclipse will be seen as partial if it is visible at all.

As the eclipse begins, the black disk of the moon begins to hide the western edge of the sun. Slowly the moon covers more and more of the sun's face; meanwhile, night appears to be falling. The last remnant of the sun's rim breaks into "Bailey's Beads," and then, as though at the snap of a switch, the pearly corona bursts into view. It is this sight that astronomers travel halfway around the earth to see and to photograph. The corona reveals characteristics of the sun not observable at other times. It is a veil-like halo surrounding the blotted face of the sun. Here and there, reddish prominences color it slightly, and long, curved streamers may arch outward all around it. Then, totality suddenly ends as the black disk of the moon begins to pass from in front of the sun. Not more than about 7½ minutes have elapsed since the spectacle began, but, short as it is, it is the thrill of a lifetime.

Due to the motions of sun, moon, and earth, two solar eclipses occur each year, and as many as five are possible.

The sun in eclipse.

Not all are total eclipses, however. Other types are partial and annular. In the latter, the moon is so situated during its passage in front of the sun that a ring of the sun is visible around the black disk of the moon.

Exercises for Problem Study and Review

1. What seven bright objects in the sky were classed as planets by the ancients? Why were they called planets?
2. How were these seven bodies and the earth thought to be arranged, according to the Ptolemaic theory? Who was the author of the theory? Did everyone of his time agree with him?
3. What false premise led to the false Ptolemaic theory?
4. Who formulated the new theory? When was it published? Why was it not published when its formulation was complete?
5. State the main points in the Copernican theory.
6. Who was Tycho Brahe? What was his great contribution to our knowledge of the sky? Did he believe in the Copernican theory?
7. Who was Bruno? What was his line of reasoning about the stars and the earth's motion? What fate did he suffer? Why?
8. Who was Kepler? State the two laws of planetary motion discovered by Kepler.
9. What procedures were employed by people of the sixteenth and seventeenth centuries in solving problems concerning the world about them? What methods would be used today? Do some people today still use sixteenth and seventeenth century methods? Explain.
10. Who was Galileo? When did he live? What did he conclude regarding rest and motion? How did he arrive at his conclusions?
11. What did Galileo conclude regarding falling bodies? How did he arrive at his conclusions? How do we explain the way in which objects of different weights fall to the earth?
12. Who was Sir Isaac Newton? When did he live? State his first law of motion and explain what it means. State his law of universal gravitation and tell what it means.
13. Is the earth falling toward the sun? What prevents it from falling into the sun?
14. With the aid of a diagram, explain how the moon goes around the earth.
15. Tell which planet (1) is nearest the sun; (2) is the Giant Planet; (3) is the earth's twin sister; (4) is the planet with a system of rings; (5) is the most remote planet; (6) is nearest to the earth; (7) is the red planet; (8) is the most recently discovered planet; (9) is the most remote planet visible to the unaided eye; (10) always keeps the same side towards the sun; (11) has the largest number of moons; (12) is the brightest planet as seen from the earth.
16. Discuss the possibility of life on (1) Venus; (2) Mars; (3) the

other planets, pointing out conditions favorable and unfavorable to the existence of life, as we know it, on those planets.

17. Explain how the scientific method was employed in the discovery of Neptune. Of Pluto.

18. Are there other planets beyond Pluto? Give reasons for your answer.

19. What did the ancients think of comets? How are comets regarded today?

20. Describe a comet and tell how comets travel around the sun.

21. Describe a "shooting star" and tell what it really is.

22. Describe Meteor Crater. What may have caused its formation? Of what interest is it today?

23. From where do meteors come? Why do we have meteor showers at certain intervals?

24. Tell why on the moon (1) the stars do not twinkle; (2) the stars can be seen in daytime; (3) the earth is "up"; (4) the earth goes through phases; (5) no speech or sound could be heard; (6) our strength would seem very much greater than on earth; (7) a day is two weeks long.

25. Why does the moon rise and set? How does it go around the sky?

26. Explain the cause of the phases of the moon. How much of the moon's surface has been viewed? Why?

27. Describe an eclipse of the moon. How is a lunar eclipse brought about? Why do we not have one at each full moon?

28. How do the sun and moon produce the tides? Which is more influential? When do neap tides and spring tides occur?

29. What is the effect of the moon on people, weather, and crops?

30. Of what is the sun composed? What is its temperature? Is the sun burning up?

31. What are some possible sources of the sun's energy? What is the leading theory at present as to this problem? What becomes of the sun's energy? How much of it does the earth receive?

32. What are sunspots? What are some of their characteristics? What effects do they produce here on earth?

33. Describe a total eclipse of the sun. What is the cause?

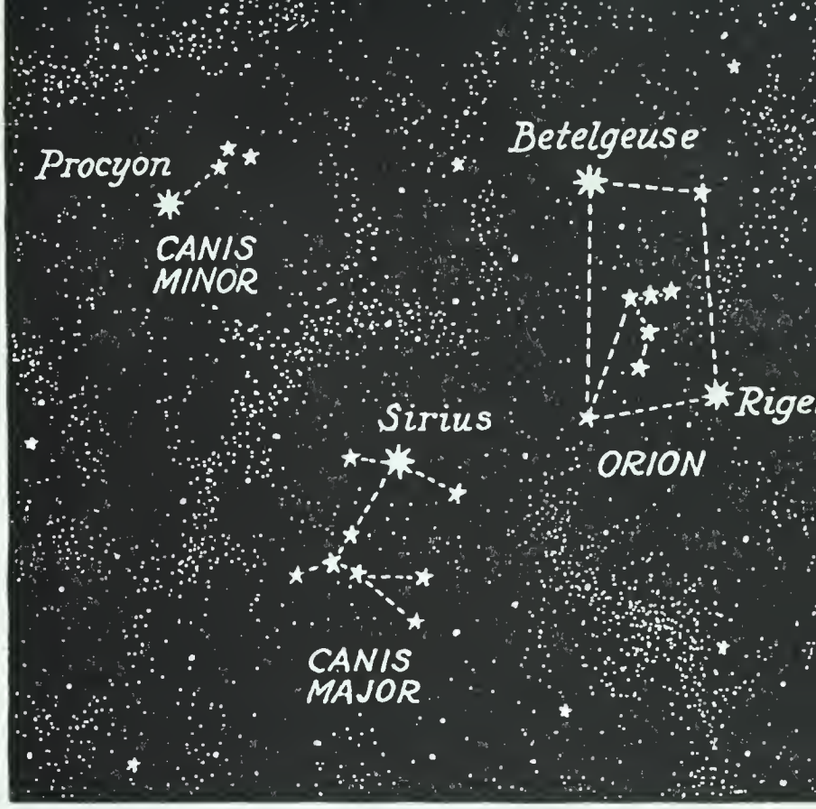
34. Which members of the solar system are self-luminous? Which ones shine by reflected light? What is the source of this light?

Problem 3: What has man discovered beyond the solar system?

Man throughout the ages has watched the sky with awe and wonder, and even for us today the starry scenery remains fascinating. Let us therefore look at the figures on the face of the sky—let us inquire what the stars themselves are like—let us consider the stars in motion.

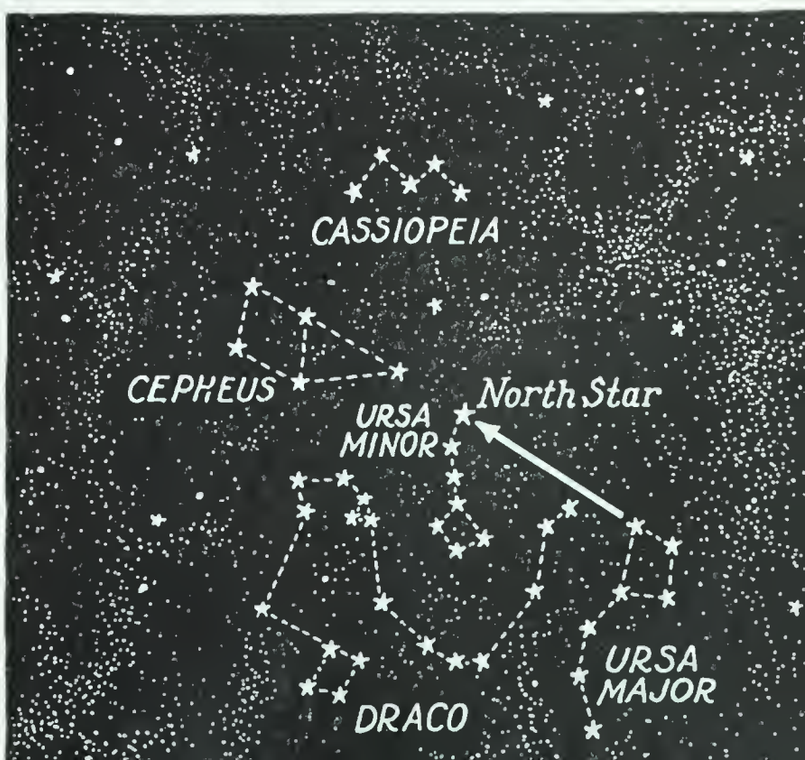
• THE STARS AND THE CONSTELLATIONS

At first glance it seems to be an endless task to learn to recognize the stars. On a clear night when the moon is not too bright and there are no near-by artificial lights to interfere, there seems to be no limit to the number of stars we can see. Soon, however, various patterns, such as crosses, dippers, triangles, V's, squares, and chains of stars, begin to stand out. Familiarity with one or two of the well-known constellations is a great help in learning the star groups. Among the better-known star patterns are the Big Dipper, the Little Dipper, Cassiopeia, and Orion. These names have survived from the time of ancient Greece, when constellations were named for characters in Greek mythology. Forty-eight such constellations were known at that time and were described in the *Almagest* of Ptolemy. Today, astronomers use many of the same names for the constellations, but they no longer use the imaginary figures assigned to them by the Greeks. Instead, the names indicate definite areas of the sky bounded by straight lines running from north to south and from east to west. Eighty-nine such constellations have been agreed upon by astronomers, and the entire sphere of the stars has been mapped in this way.



These star groupings of the winter sky are familiar to thousands of star-gazers.

If you want to learn to know the constellations, provide yourself with a star map or a book of the stars and a flashlight, preferably one that throws a strong, narrow beam so that it can be used as a sky pointer. It is an advantage to have someone already familiar with the sky to help you get



The well-known circumpolar constellations below are found near the North Pole.



J. C. Smith, Colby College

This beautiful picture of star trails was made by pointing the camera, shutter open, directly at the North Star and by leaving the camera alone for a while. How could you calculate the exposure time from this picture? Is this adequate proof that the earth rotates on its axis?

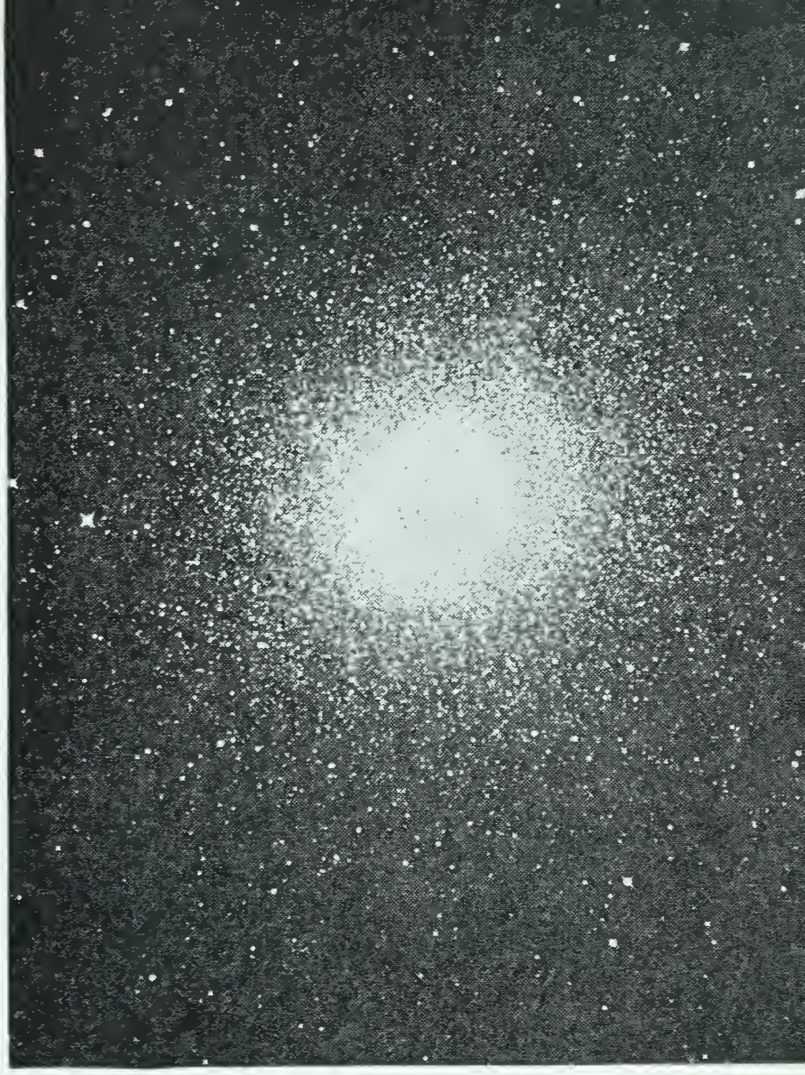
started. Any time of the year is a good time to begin; you do not have to wait for any particular season.

First, select some constellation you already know, locate it on your star map for the present season, and work outward in all directions from this point. If you do not know any of the constellations, find the group of seven stars forming the well-known Big Dipper. The two stars opposite the handle in the bowl of the Big Dipper are known as the pointers, because a line drawn through them and extended about five times as far comes almost directly to Polaris. This star is also known as the polestar, or North Star, because it is located almost directly above the north end of the earth's axis; the sphere of the sky seems, therefore, to turn around Polaris. Polaris is at the end of the handle of the Little Dipper, and if you look closely, you will be able to find the seven stars in this constellation.

It is beyond the scope of this text to give directions for locating all of the constellations—that would require a fair-sized book in itself. If your appetite for stargazing has been whetted, get yourself a guide to the stars and continue; you should really give an hour or two to observation of the sky every few nights throughout the year if you want to see the complete picture.

Some people are disappointed to learn that the number of stars to be seen at any one time by the best eyes and under the best conditions is only about three thousand. The total number visible throughout the year is about seven thousand. But telescopes and photographs reveal more and more stars in our star system. Astronomers now estimate that our galaxy probably contains at least one hundred billion stars. These stars are arranged roughly in the

form of a huge watch. Our sun is one of these stars, and we are on a planet revolving around the sun. Consequently, we can look through the watch edgewise, or toward either face of it. When we look edgewise through our galaxy we see several times as many stars against the blackness of space beyond as when we look out into the sky in other directions, and we call it the Milky Way.

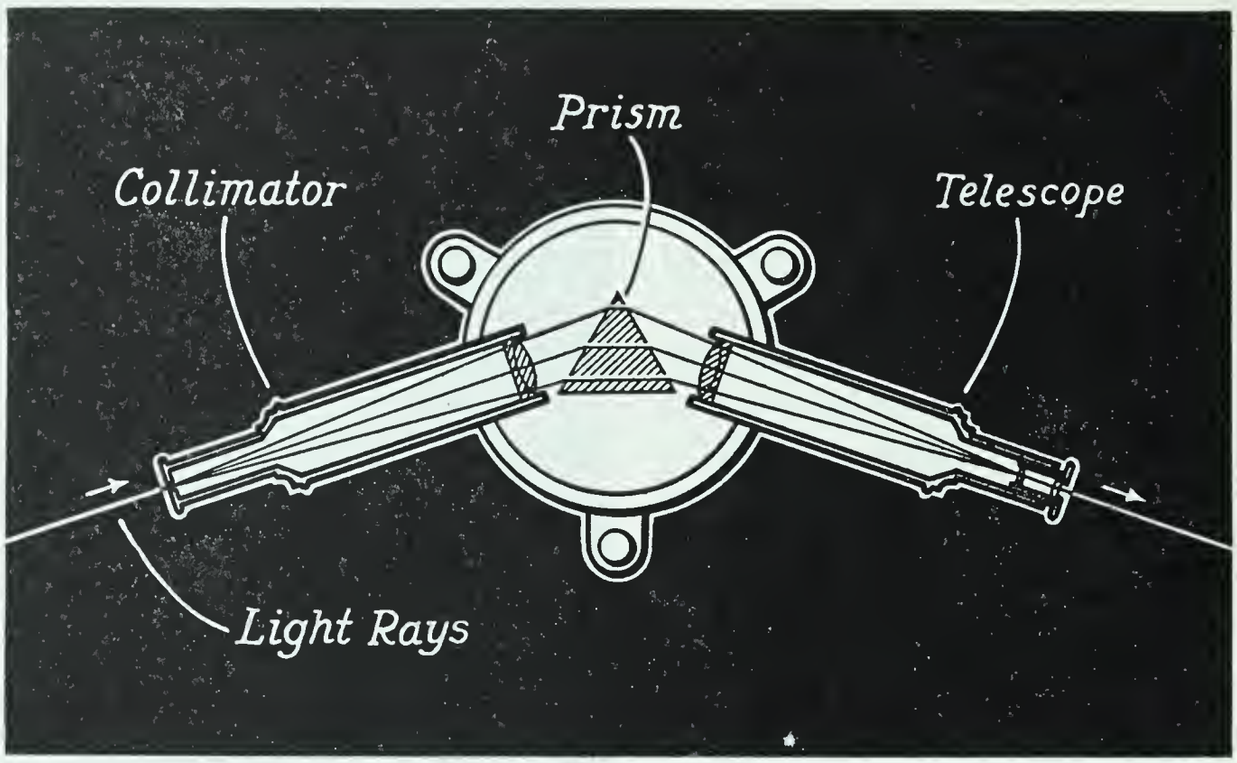


Courtesy Mount Wilson Observatory

What the unaided eye sees as a patch of light in the constellation Hercules becomes through the use of the telescope a great star cluster composed of about one hundred thousand suns which are over two hundred quadrillion (200,000,000,000,000,000) miles away from us in space.

The telescope reveals that many stars which appear to be single stars when viewed by the unaided eye are really very complex. Some are doubles—that is, pairs of stars which mutually revolve around each other; triples and even double doubles are known. Stars also form clusters. One of the best known compact clusters of the northern skies is the great globular cluster in the constellation, Hercules. To the unaided eye, it appears to be a rather faint star, but the telescope reveals that it is a grand assemblage of perhaps one hundred thousand stars—each a blazing sun one thousand times as bright as our own. The Pleiades, or Seven Sisters, and the Hyades are examples of open star clusters.

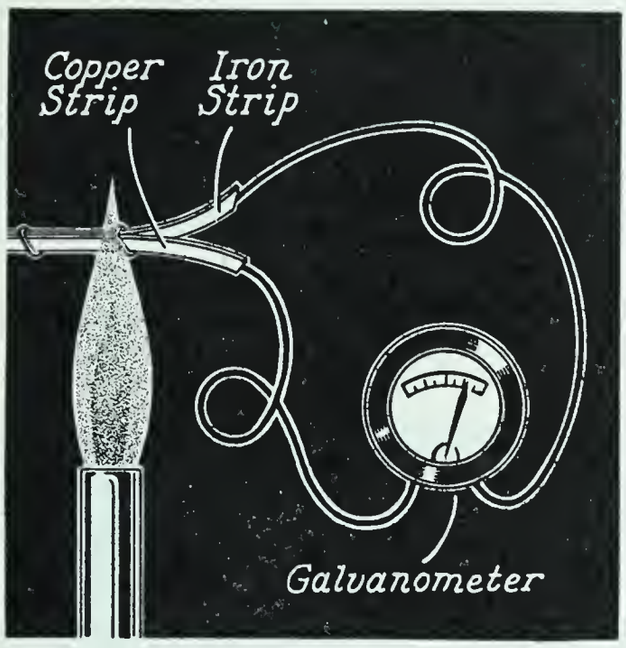
Anyone can see that the stars differ in brightness. We can readily advance several hypotheses for explaining the variations. Perhaps they differ in size; perhaps some are hotter than others; perhaps their distance from us is a factor. Astronomers tell us that all of these are real causes of the differences in brightness. If the stars are remote suns, how would they appear to us if put in the sun's place? For the most part, they would be very similar, both in size and brilliance, but there are exceptions, of course. Some are giants and a few are supergiants. Red Antares, which can be seen in the heart of the Scorpion low in the south in the summer,



The spectroscope reveals that the entire universe seems to be made of the same fundamental kinds of matter.

is an example of a supergiant; it has a diameter of about four hundred million miles. Betelgeuse and Rigel in Orion, and Deneb at the top of the Northern Cross are others. In 1938, announcement was made of the discovery of the largest star known to man. It is estimated to be twenty-two to twenty-seven billion times the size of the sun. If this star were dropped into the center of our solar system, there would be no room for Mercury, Venus, Mars, Earth, or Saturn; it would fill up all of this space and overflow halfway to the orbit of Uranus. At the other extreme are the dwarf stars. Sirius, the Dog Star, has a faint companion which is a typical dwarf. This dwarf is about the size of the earth but weighs about as much as any of the other stars. The stuff of which it is made must therefore be packed together very closely. It is estimated that a cubic inch of the "stardust" from this star would weigh almost a ton!

At this point, you would probably like to inquire, "Of what materials are these stars made?" Astronomers learn of the composition of stars and other heavenly bodies by using an instrument called a *spectroscope*. The chief part of this instrument is a glass prism which separates the starlight into a band of colors resembling those of the rainbow. In addition, there are dark lines across the band of colors, and their positions give the answer to our question. When lines appear in certain places, astronomers



The thermocouple is used to measure the temperatures of the stars.

know that certain chemical elements are present in the star. By means of the spectroscope scientists have found that hydrogen, helium, iron, calcium, and other elements found on the earth also compose the stars. At star temperatures all are in the gaseous condition. As yet, no elements have been discovered in the stars or other heavenly bodies that are not present in the earth itself; the entire universe seems to be made of the same fundamental kinds of matter.

The stars shine because they are extremely hot. Neon gas glows when it is sealed in a glass tube and subjected to a high-voltage electrical discharge. Sufficient heat would have the same effect as the electric current. The gases in the stars are hot enough to glow in this fashion. How the high temperatures are maintained throughout the ages, no one knows. But glow, they do—and with different colors. Observe some of the brightest stars. See if Betelgeuse in Orion does not look reddish and Rigel, diagonally across the constellation, blue; see if you can detect a yellowish glow from Capella and a reddish-yellow glow from Aldebaran in the Hyades. Vega and Sirius are both blue stars; Arcturus has an orange hue. None of these colors is as brilliant as those of Christmas-tree lights, but if you look carefully, you can detect them nevertheless.

Star colors result from their temperatures in the same way that a piece of iron gives off various colors at different temperatures. The red stars are coolest; the blue stars are hottest. Our sun is a yellow star of medium temperature. The great star discovered in 1938 is a "dark star," too cool to shine with visible light; its temperature is only about 1,000° centigrade.

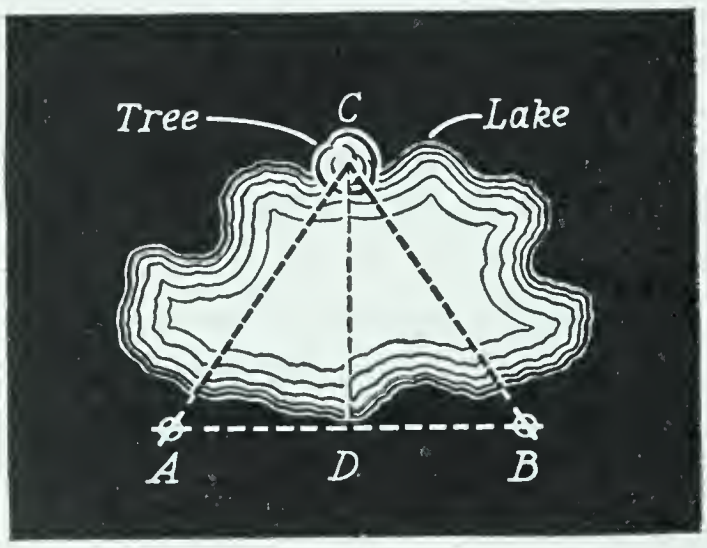
Star temperatures, in general, are measured by the use of instruments involving the principle of the *thermocouple*. The thermocouple consists essentially of two dissimilar metals, such as copper and iron, joined together. When the junction of the two metals is heated, an electric current is produced—the higher the temperature, the greater the current. From measurements of the current

produced at *known* temperatures, a scale has been devised so that *unknown* temperatures can be inferred from the size of the currents they produce. Thermocouples have been adapted to measuring the slight heat that reaches the earth from distant stars, as well as the intense heat of furnaces which would melt the glass and boil the mercury of ordinary thermometers. While the thermocouple provides a means of transforming heat energy directly into electrical energy, the process is inefficient, and its practical applications are few.

The twinkling of the stars is caused by our atmosphere and not by any characteristics of the stars themselves. Because they are so far away, the stars act as points of light. This light is turned aside, or is turned on and off by air currents in the atmosphere, and the effect is called twinkling. In the case of the sun, the moon, and the nearer planets, we see disks of light rather than points; hence they shine with a steady glow.

• STAR DISTANCES AND STAR MOTIONS

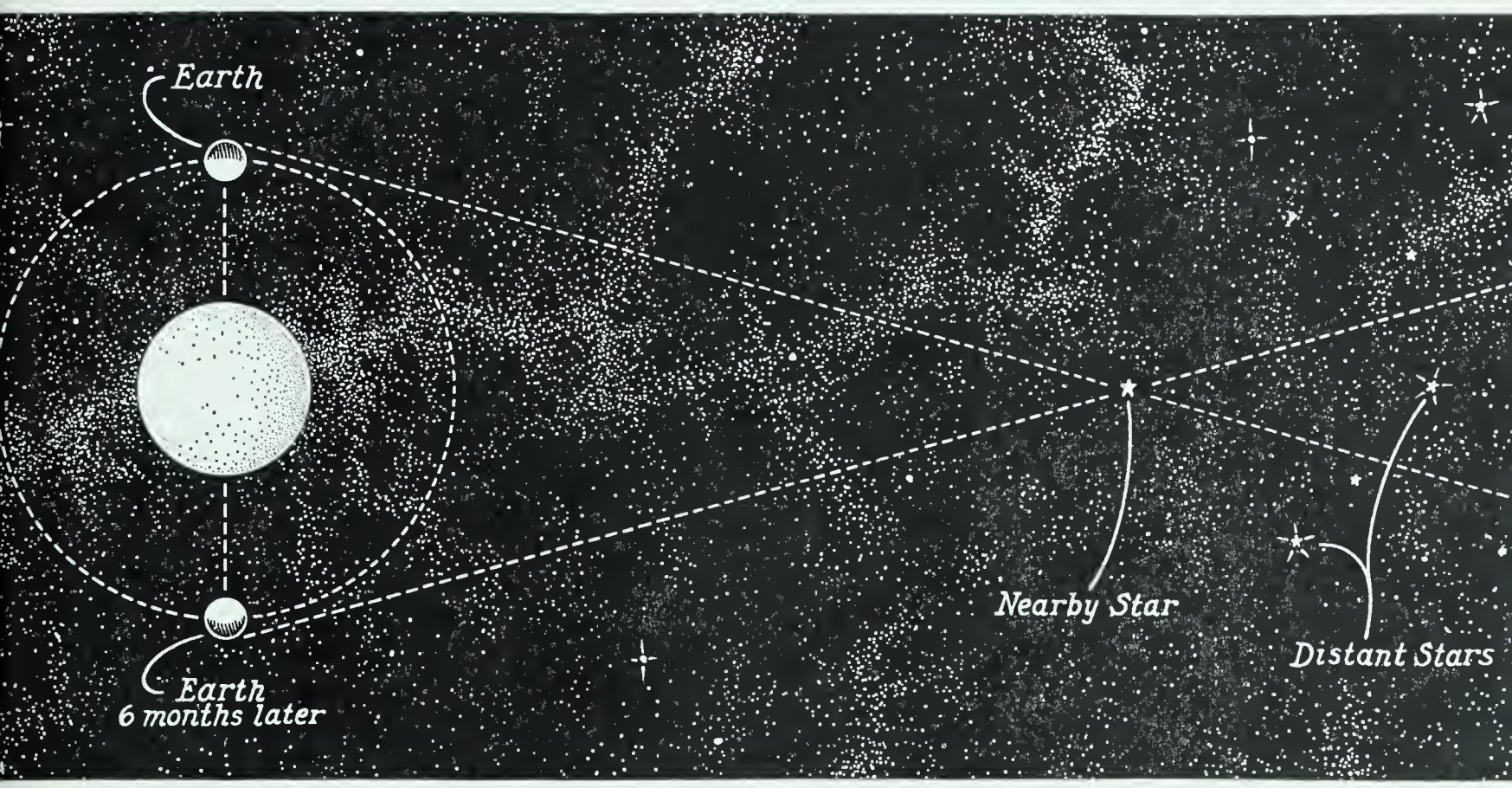
To be as large as they are and appear as small as they do, the stars must be extremely far away. Their distances are too large to be expressed conveniently in miles; instead, astronomers use the *light-year* as the unit for expressing distances in interstellar space. Light travels about 186,000 miles a second; in one minute it travels sixty times this far. If we multiply this number by 60 to find the distance it travels in an hour, then by 24 to find the distance in one day, and finally by 365, we would have the number of miles a ray of light travels in one year. The answer is about six million million miles; this is the light-year. Our nearest neighbor among the stars is Proxima Centauri, a very faint star in the southern celestial hemisphere; it is 4.3 light-years distant, or about twenty-five million million miles away. Sirius, the brightest star on the face



How wide is the lake from point D to C? The surveyor answers this question by sighting an object such as the tree at C from two remote points, A and B. He measures the angles at A and B and also the distance AB. By constructing a triangle to scale, he easily finds the distance DC.



The nearness of the moon makes it possible to determine its distance by applying the method of parallax from two places on the earth itself.



The remoteness of the stars makes necessary a very long base line when applying the method of parallax to determine their distances.

of the sky, is nearly 9 light-years away. Most of the stars are much more remote than this.

Perhaps the most interesting thing about star distances is the way in which they are determined. The *method of parallax* employed is illustrated in the diagram on page 246. To make possible the application of this technique to measuring star distances, a very long base line is needed, because the stars are so far away that any base line drawn on the earth's surface would be too short. Sight lines to the stars from sets of points on earth seem to be parallel. Astronomers have solved the problem by using as their base line the diameter of the earth's orbit, which gives them a line about 186,000,000 miles long. The apparent location of the star to be measured is observed at one time of the year and again six

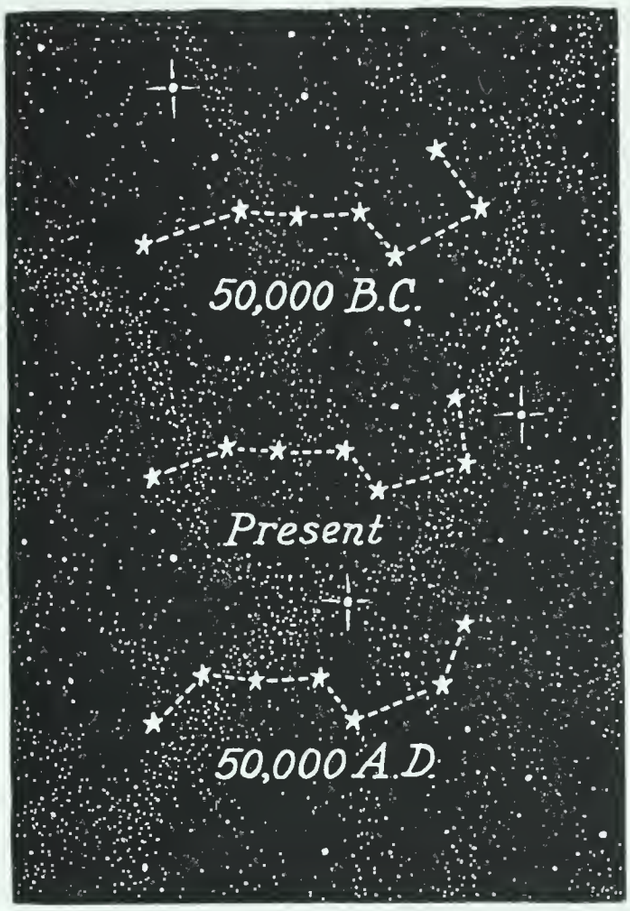
months later. In each case, the angle between the sight line and a line to the sun is determined. Then, by drawing a triangle to scale or by mathematics, the star's distance can be figured. This method is theoretically accurate for distances up to about 100 light-years; for greater distances, other methods and instruments too complex to be described here are used. The same principle can be applied to determine the distances to other heavenly bodies —the planets, the sun, and the moon. In the case of the moon, observations are made simultaneously from stations at a considerable distance apart, as New York and San Francisco. The base-line distance is known, and when the two angles between this line and the moon's direction are measured, a triangle can be drawn to scale and the moon's distance calculated.

The star figures on the face of the sky seem to be fixed and unchanging. For more than two thousand years, man has watched the Big Dipper, Orion, Cassiopeia, and other constellations and has detected no change in their form or arrangement. Yet astronomers tell us that the stars are moving at tremendous speeds—some at more than 20 miles a second. But the stars are so distant that our eyes are unable to detect their motions; in fact, the most sensitive astronomical instruments are barely capable of proving star motion. In time, however, the familiar star groupings will change and take on new forms and designs. The time required to make changes noticeable to man is probably about one hundred thousand years! Our sun is a star in motion; it and the planets are speeding toward a point in the constellation, Hercules, at a velocity of about 12 miles a second.

Since there are billions of stars out in space, all rushing along at such high speeds, we might wonder if collisions ever occur. If so, how often? Astronomers are not positive just what the answer is. Because space is so vast, astronomers believe collisions occur very infrequently—perhaps at the rate of one collision in a quadrillion years! A near collision of our sun and another star is believed by some astronomers to be a plausible cause of the formation of the solar system. According to this hypothesis, the close passing of the two stars produced huge tides in the gaseous stuff composing them. Great spinning masses were torn from the sun, which, upon cooling throughout millions of years, formed the planets.

All through the ages, man has wondered how the earth and solar system came into being. Many explanations have been set forth. One early belief still held by many people is that all of the

materials of the earth—the different kinds of rock, the soil, fossils, coal, petroleum, and so on—and all of its great variety of inhabitants were created almost at a single stroke and in essentially their present form. This explanation was developed out of the imagination of men who lived long before scientific facts and evidence were available. Today, people who are guided in their thinking by the scientific attitudes are not content to accept on faith such unscientific and fanciful explanations. They believe that our knowledge of astronomy and the story told by the rocks, minerals, and fossils of the earth's crust are safer guides to truth. The present tidal-wave theory of the origin of the earth and solar system takes into account the facts of astronomy, but as new knowledge is discovered, this hypothesis may change. Science teaches us that man's idea of truth is never final and complete, but changing, and that we should assume a critical attitude towards our beliefs and be willing to change them when the evidence demands change.



Over a period of time, star groupings change and take on new forms and designs. This shows how the Big Dipper has appeared differently in the past and will change in the future.

• BEYOND THE MILKY WAY

More powerful telescopes have enabled astronomers to explore farther and farther into outer space—and the things learned stagger the imagination. We now know, for example, that beyond our Milky Way are other great star systems, perhaps millions of them, similar to our own galaxy.

For many years, hazy patches called nebulae have been recognized in the sky. With the development of telescopes, many of them proved to be star clusters, while others really proved to be foggy regions far, far away. Such clouds of glowing dust and gas



Courtesy Yerkes Observatory

The great spiral nebula of Andromeda to the naked eye is a faint, hazy patch of light; to the telescope, it is an island universe containing millions, possibly billions, of individual stars.

also exist within our galaxy, but it is the outside ones we wish to consider now. The brightest of these nebulae is the great nebula in the constellation, Andromeda. It is not a part of the constellation, but in order to see it we look out toward and beyond this group of stars. The Andromeda nebula can be seen with the naked eye, to which it appears as a faint, hazy patch. When photographed through large telescopes, it was found to be a brilliant oval with two luminous, projecting arms partially wrapped around it like a spiral. This form seems to be typical of the external galaxies, more than three-fourths having this pattern.

Astronomers tell us that the Andromeda nebula is really a galaxy like our own, shining with the combined light of millions of individual stars. It is the most distant heavenly object that can be seen by the unaided eye, being about 930,000 light-years away. But even at this great distance, it is the second closest external galaxy; the closest one is too faint to be seen without a suitable telescope. The Andromeda nebula seems to be approaching the earth at a speed of 200 miles a second, but in this respect it is not a typical nebula. Most of them are speeding away from the earth and our galaxy at tremendous velocities. One group of galaxies, for example, viewed through the constellation, Gemini, is receding at the dizzy speed of 15,000 miles a second.

The farther away the galaxies are, the faster they travel. What is the cause of such behavior? Why should they keep on increasing in speed as they get farther apart? What force acts to increase constantly the speed of the galaxies?

The preceding questions bring us very near the frontiers of astronomical knowledge and investigation. Astronomers themselves do not know the answers, but they have set forth some interesting hypotheses that still remain to be tested. One interesting idea is the possibility that, in addition to attracting each other according to Newton's law of gravitation, every body in the universe *repels* every other body with a force that increases as they get farther apart. When close together, bodies repel each other with a force so small as to be negligible, but at the distances prevalent among the galaxies the forces could become very large indeed. As a consequence, the motions of the galaxies would be affected in proportion.

Where are the limits of space? How far do the galaxies extend? How far apart can they get? These questions bring us to the idea of an "expanding universe." It has been suggested that space has a limit, but that the limit is ever receding and getting farther away

in every direction. As one astronomer presents the idea, "Imagine some spots on a balloon that is being inflated. From any one of these spots the others are moving away; and the farther they are from a particular spot, the faster they move away from it."[1]

Whether or not these ideas are correct is a problem that may require many years to answer. Perhaps the 200-inch telescope at Mt. Palomar will provide the necessary information, for its chief job is to aid man in his exploration of outer space. With additional information, man will extend these hypotheses about the nature of the universe, modify them in terms of the newer knowledge, or discard and replace them with new ones. Such is the nature of impartial, objective, scientific investigation as a means of satisfying man's burning desire to know the truth about himself and his universe.

Exercises for Problem Study and Review

1. Under what conditions can the stars and constellations best be studied? Why?
2. Why does the northern sky seem to turn around Polaris? In what constellation is this star situated? How can Polaris be located in the sky?
3. How many stars can be seen at one time under the best conditions? How many stars are bright enough to be seen with the unaided eye?
4. What is the Milky Way? How many stars are estimated to be in our galaxy? What is the place of the sun and the earth in this system?
5. What are double stars? Globular clusters? Open clusters? How has their discovery been made possible?
6. What hypotheses can be set forth to account for variations in star brightness? Discuss the probability of each hypothesis.
7. How does our sun compare with other stars as to size? State an interesting fact about the companion of Sirius, the Dog Star.
8. How do astronomers study the composition of stars? Tell briefly what they have learned about the composition of the heavenly bodies.
9. Why do the stars shine? Why do they twinkle? What causes their colors? How are star temperatures measured?
10. How far away are the stars? Are they all equally distant? What is the name of the nearest star? What is a light-year?
11. How do astronomers determine star distances? What base line do they use? How would this method be used to determine the moon's distance?

[1] Baker, Robert H., *When the Stars Come Out,* The Viking Press. By permission of the author and the publisher.

12. Compare the sky of today with the sky of two thousand years ago; with the sky of one hundred thousand years hence. Is our sun in motion? How does this affect the earth and other members of the solar system?

13. Are stars believed ever to collide? What has such a possibility to do with the formation of the solar system?

14. Are there other Milky Ways besides our own? What evidence leads to this conclusion?

15. What is the most distant object in the sky visible to the unaided eye? How far away is it? How does it appear through a telescope? How is it moving?

16. What hypothesis has been offered to account for the increasing speed of the galaxies as they get farther away?

Problem 4: How do we use our knowledge of the sky?

The idea of the elapse of time between events is as elementary as the recognition that there is distance between places. To say that a runner travels one hundred yards takes on new significance when we learn that he was able to cover this distance in ten seconds. It is in terms of these two fundamental concepts, *time* and *space,* that we understand a multitude of events in the world about us. Such units as the inch, foot, yard, and mile represent the end result of a long period of conscious effort on man's part to apply exact measurement to distance; likewise, the second, minute, hour, day, and year are typical units evolved by man to measure the passage of time accurately.

• THE CLOCK IN THE SKY

The search for a satisfactory answer to the simple question, "What time is it?" leads to interesting applications of astronomy. It was to the sky that man first turned for the answer to such questions. The sun, which brought alternate periods of daylight and darkness by its rising and setting, became man's first timekeeper. Day and night were natural, big units of time; it was easy to divide the day into smaller parts according to the relative positions of the sun as it traveled from east to west across the sky. The time when it was directly overhead, of course, was called noon, and this divided the day into the A.M., before noon, and the P.M., after noon.

Since the time of Copernicus, we have come to realize that it is really the west to east rotation of the earth on its axis that counts

out the days and indicates the time of day. Astronomers tell us that the time required for one complete rotation of the earth—that is, our day—is gradually increasing by as much as one one-thousandth of a second in a hundred years, and that it may sometimes vary for other reasons by as much as half a minute. However, our best clocks do not approach this degree of uniformity, and the rotating earth is accepted as the master clock of our universe.

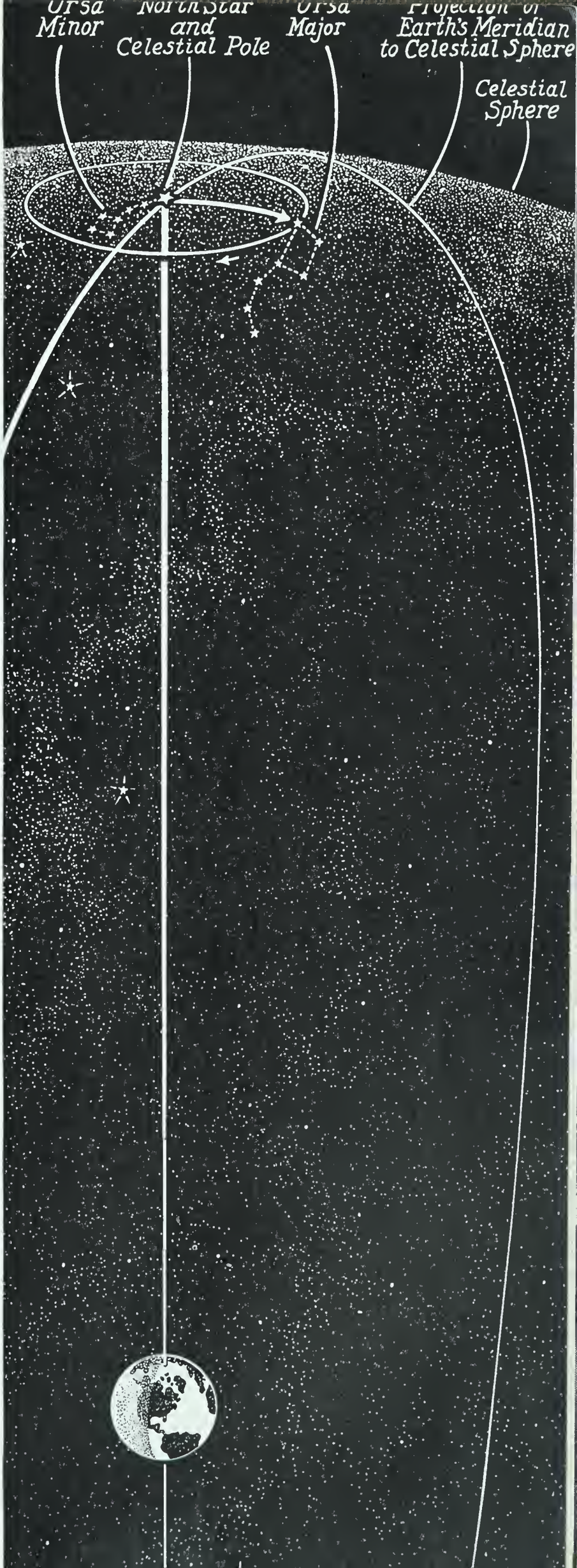
Astronomers check the accuracy of timepieces by reference to a huge clock on the face of the sky. As we have already learned, the sky apparently rotates from east to west because the earth rotates from west to east. This apparent rotation of the heavens takes place about an axis which is an extension of the earth's axis at each end out into space. Each end of this axis thus locates on the celestial sphere a stationary point called a celestial pole. Because of its location near one end of this imaginary axis, the North Star appears to remain fixed, while stars farther from the celestial pole seem to rotate. Thus, if we imagine a straight line drawn from the North Star to one of these rotating stars, the end attached to the moving star would describe a circle during one complete rotation of the earth on its axis. This is somewhat analogous to the simple method of drawing a circle on a blackboard by using a string to one end of which is tied a piece of chalk.

If we consider this circular area as the face of our sky clock, we can gain an insight into the method by which the astronomer answers the question, "What time is it?" The outer end of the imaginary line from the North Star forms the hour hand, indicating the time by its motion around the circumference of the face of the clock. The next task is to locate some point on this circumference so that we can check the exact time at which the hour hand seems to cross it. The interval between two consecutive crossings, or transits, would be twenty-four hours, representing one rotation of the earth on its axis. To locate this reference point astronomers make use of what is known as a celestial meridian. A meridian on the earth

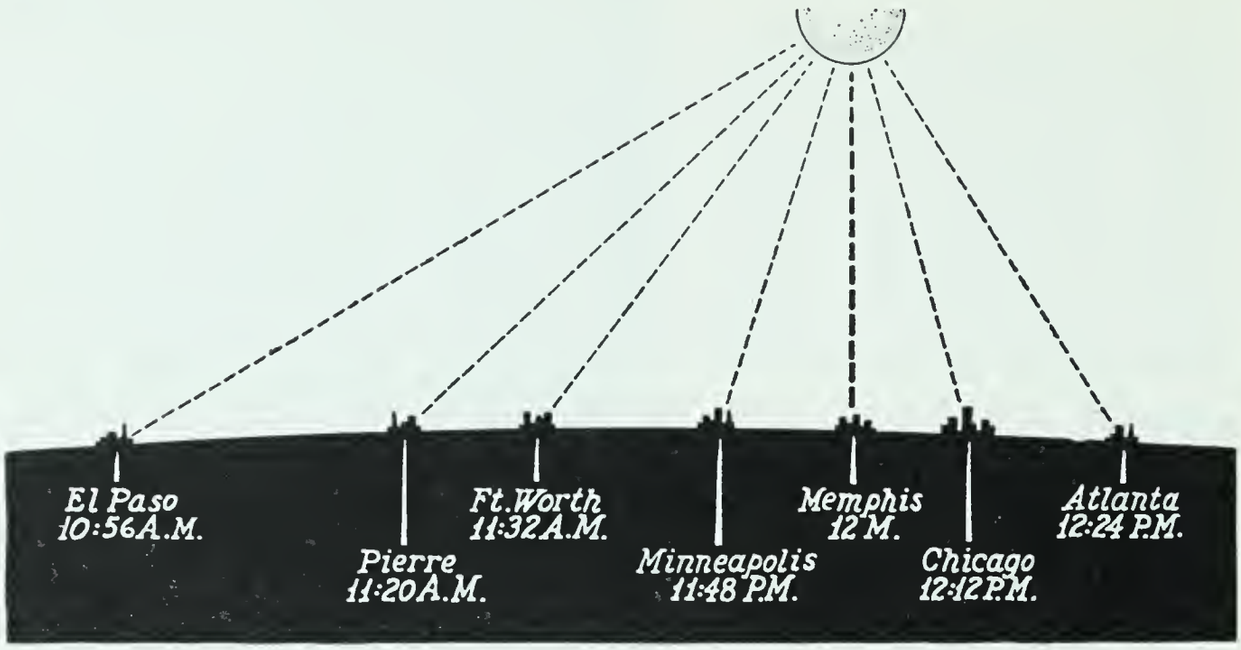


is an imaginary semicircle extending from the North Pole of the earth to the South Pole. Similarly, a celestial meridian is an imaginary line curving from the north celestial pole around the seeming sphere of the sky to the south celestial pole. Such a semicircle intersects the circumference of the face of our sky clock, thereby furnishing the desired reference point. With the aid of astronomical tables which record the accepted time when the observed star seems to cross each particular meridian, a trained observer can obtain the correct sidereal time, or star time, from the sky.

Astronomers obtain the correct sidereal time in this fashion, except that instead of observing a star, an easily located position in the sky called the vernal equinox is used. Standard observatory time is the name given to the time obtained directly from the star clock in the sky.



The clock in the sky might appear like this from outer space. The imaginary hour hand counts out the hours as the earth turns under it. The celestial meridian, a projection of an earth meridian, really turns past the fixed star. From the earth the star seems to cross a "fixed" meridian. The time interval between two consecutive crossings is called 24 hours, or one day.



If their clocks were set by sun time, the cities above would have the times indicated. However, since they are all in the Central Standard Time Belt, they must take the solar time of the 90-degree meridian, which happens to pass through Memphis.

For regulating his everyday affairs man finds it more convenient to set his clock by the sun. Noon, for example, by sidereal time would only occasionally be the time when the sun was directly overhead. This would occur only when the sun and vernal equinox crossed the celestial meridian together as observed from a common point. Since the earth rotates once in a sidereal day, the vernal equinox would again cross the meridian twenty-four hours later. The sun's next crossing, however, lags by about four minutes because of the distance traveled in the meantime by the earth in its revolution around the sun. This difference between the occurrence of solar noon and sidereal noon becomes for a time progressively greater until a time is reached when sidereal noon occurs during our nighttime. For this reason we prefer to use solar time even though added adjustments are necessary to make solar time uniform and reliable.

The difficulty encountered in using the sun as a standard when obtaining the time arises from the nonuniform speed of the earth in revolving around the sun. This causes the lapse of time between one solar noon and the next to vary throughout the year. Although there are changes in the speed of the earth's revolution around the sun, the average speed for a *complete* revolution remains constant. This explains why the length of the year remains constant at a little less than three hundred sixty-five and a quarter days.

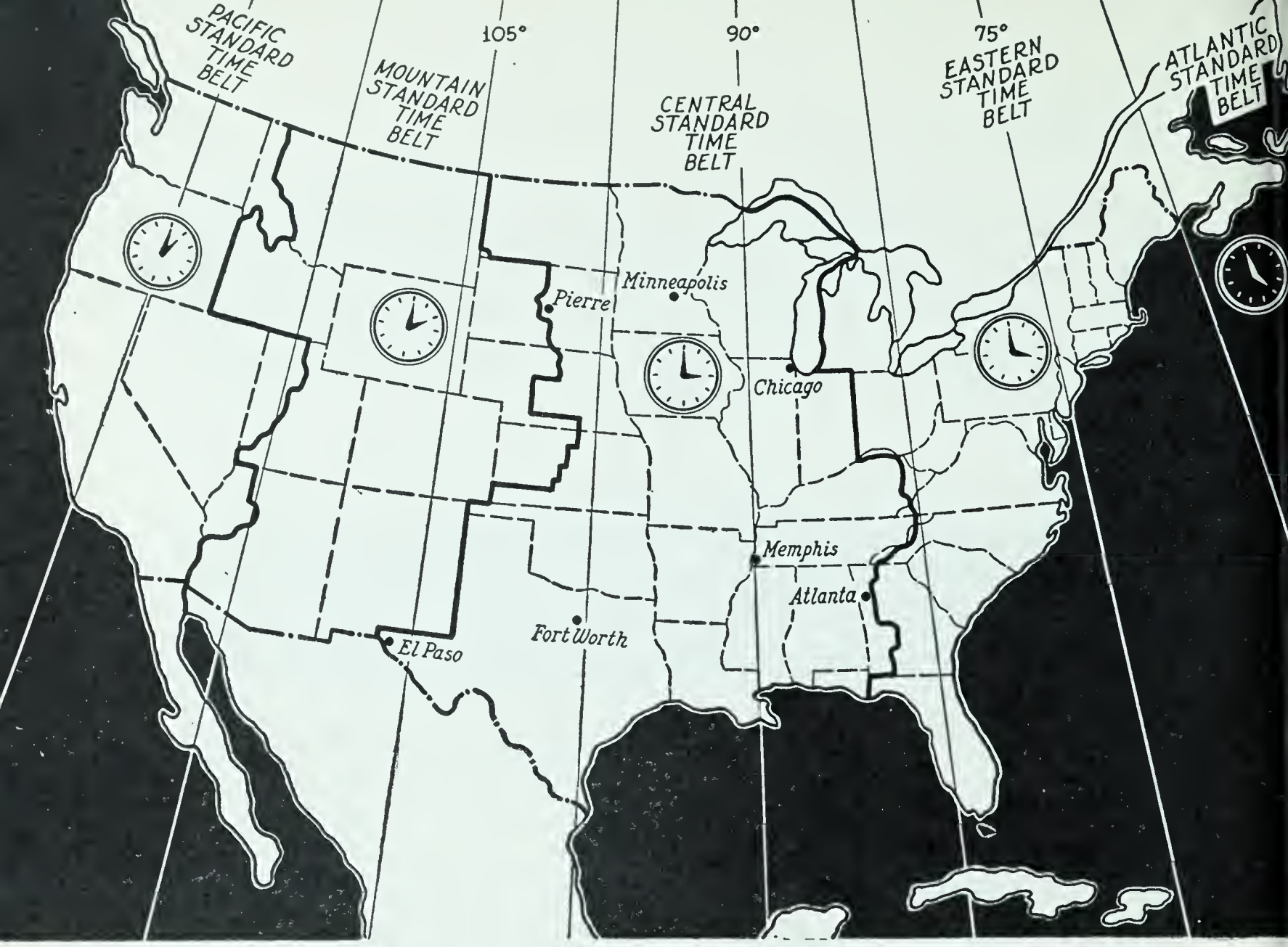
To get a common unit which does not change in size, man has taken for the time unit which we call a day, the *average* of the lengths of all of the solar days throughout the year. In other words, he has invented an imaginary sun whose uniform motion counts out days of twenty-four hours each. Time calculated on this basis is called mean, or local, solar time.

• TIME BELTS AND THE INTERNATIONAL DATE LINE

Clocks set by the sun would give a different reading for all places east or west of each other. Since solar time is obtained from the passage of the sun across a particular meridian, it is obvious that only places on the same north-south line or meridian of the earth will have the same time of day at the same moment. When it is noon at localities on a certain meridian, towns to the west will be recording the time A.M. and those to the east P.M. Noon has not yet arrived on one side and has gone by on the other. In the United States, if you set your watch by the correct local solar time and then traveled west or east a distance of twelve miles, you would find your watch differing by one minute from the correct solar time of this place.

Prior to 1883 this wide variance in time from town to town was a source of great inconvenience to travelers. Each railroad system ran its trains according to the local solar time of some chosen meridian. If local solar time were used today, what a task it would be for the radio announcer to give the correct times for even a fraction of the towns within the area served by his station! An announcement such as we hear today, "The time is now 11:30 A.M." would be meaningless without mathematical modification, except to the locality where it was made and other places which happened to be located due north or south on the same meridian.

Our government adopted "standard time" in 1883, chiefly to make traveling by railroad more convenient. The surface of the United States was divided into four time belts by irregular lines having a general north-south direction. All towns within a given standard time belt have the same time at any instant. This time is the mean solar time on the meridian which passes approximately through the center of the belt. The 75th meridian, passing through Philadelphia, was chosen to govern the time for the Eastern time belt, the 90th meridian for the Central time belt, the 105th meridian for the Mountain time belt, and the 120th meridian for the Pacific time belt.



Sun time would be different for all places east or west of each other. Standard time gives all towns within a certain belt the same time.

A difference of 15° between meridians on the earth's surface represents one twenty-fourth of the distance around the world on any circle parallel to the equator. Since the earth rotates once each twenty-four hours, places on two standard meridians 15° apart differ in local solar time at any instant by just one hour. Consequently, there is a difference in time of one hour as we pass from one standard time belt to one adjacent to it.

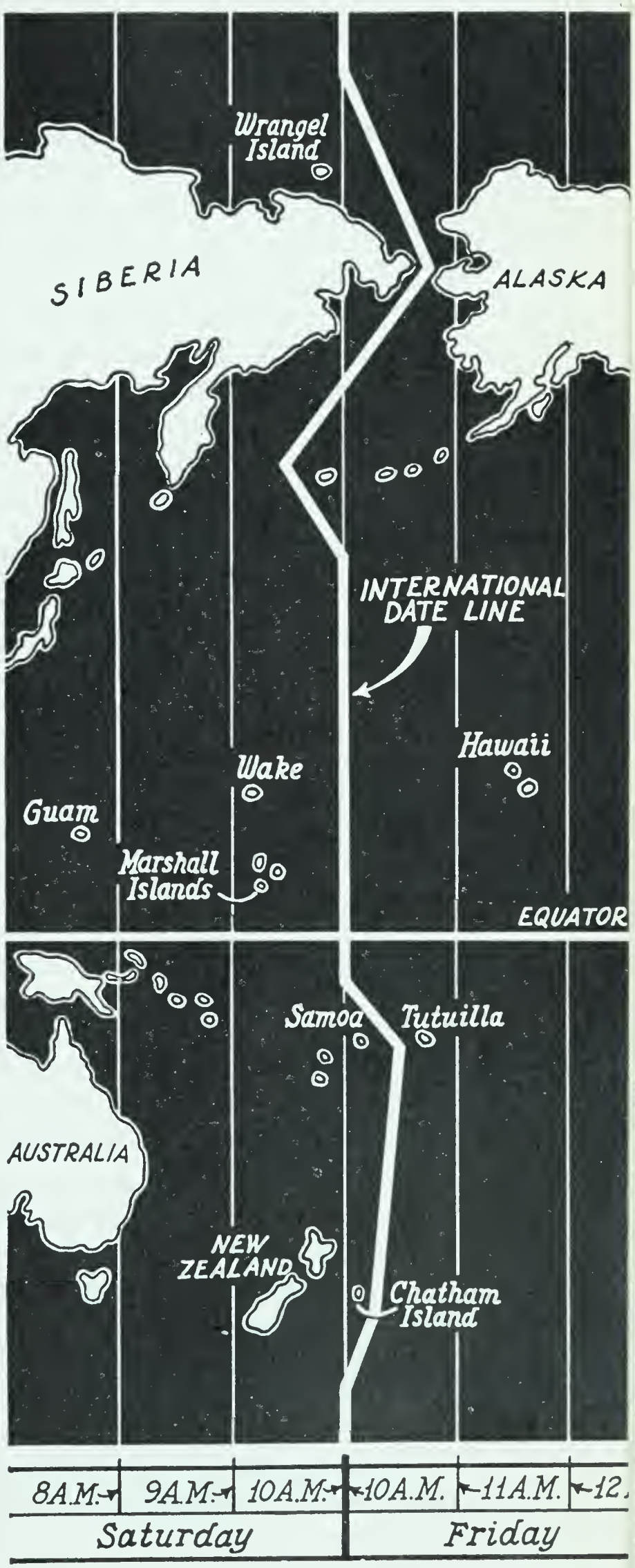
The entire surface of the earth has been divided into twenty-four standard time belts, since standard time is now used by nearly all civilized nations. Boundaries between the belts are irregular because the requirements of railroads and preferences of localities and states were taken into consideration when they were located. If a boundary is crossed while traveling eastward, time is put ahead one hour; if crossed while traveling westward, time is put back one hour. In going to San Francisco from New York City, where standard time is exactly three hours later than in the former city, setting one's timepiece back one hour at each of the three boundaries crossed is the only time correction necessary. This is certainly a big improvement over the earlier situa-

tion where practically every town had local time differing from that of other towns lying to the east or west.

If one circled the globe and made twenty-four time changes as he crossed the standard time belt boundaries, he would have either gained or lost exactly a day by the time he returned to his starting place. Whether it was a twenty-four hour gain or loss, of course, would depend upon whether he traveled in an easterly or a westerly direction.

It is evident that somewhere in his journey around the world, the traveler must change the day of the week and the date by one full day. The present custom is to make this change at the 180th meridian, which is halfway around the earth from the prime meridian of Greenwich, England. If it is 10 A.M. Friday when the meridian is reached while traveling westward, it is 10 A.M. Saturday when the line has been crossed. In journeying eastward the time change would be to 10 A.M. Thursday, and there would then be two Thursdays in succession.

Fortunately this international date line, as it is called, passes mostly over the Pacific



The traveler gains or loses one full day when he crosses this line.

Ocean and prevents the serious inconvenience that would arise if it passed through some country. If such were the case, the people on one side of the line would have a different day of the week from the day the people on the other side have, unless some adjustment were made. Indeed, the present date line does not follow the 180th meridian strictly for this very reason. It has been turned to one side where the meridian crosses groups of islands. For example, New Zealand and the Chatham Islands have the same time and date, although the 180th meridian divides them.

Time travels westward around the earth from one time belt to the next. As the earth turns, midnight, for example, shifts in the United States from New York to Chicago, then to Denver, and ultimately on to San Francisco in one-hour steps. During a twenty-four-hour period, midnight completes its world tour and returns to its starting place to begin another day. The international date line is the place where the passage of midnight officially ends one day and begins the next. Suppose a new day, let us say Monday, has just been born in the Chatham Islands near the date line. It races westward at almost 1,000 miles an hour and subsequently makes a fresh start in each of the other twenty-three standard time belts at one-hour intervals. Perhaps the best way to appreciate the westward flight of time is to listen to New Year's Eve radio programs, which keep pace with the new year as it passes from Europe, speeds across the Atlantic to New York, and thence to Chicago, Denver, San Francisco, and on to the Hawaiian Islands.

When starting in the last belt, Monday holds sway over the entire earth. To be sure, the hour of Monday is different in each belt. Moreover, its complete domination lasts but a moment, because midnight is crossing the date line again and Tuesday is about to begin in the first time belt. But the replacement is a gradual one, and another twenty-four hours pass before Tuesday gains undisputed rule by pushing Monday from its last stronghold. Therefore, as you have just seen, each day holds at least some part of the earth in its grip over a forty-eight hour period. However, its rule in any one place lasts just twenty-four hours.

• KEEPING TRACK OF TIME

While man was developing ways of obtaining the time of day from the sun and stars, he was also inventing devices for keeping track of time after it had been determined. To avoid confusion, it became increasingly important that appointments be kept promptly at times fixed in advance.

The first timepiece which man used to help regulate his daily economic and social affairs was the sundial. The idea upon which it is based no doubt came from the discovery that some natural high-standing object, like a tall tree, indicated the passage of time by the change in the length of the shadow which it cast during the day. In the early sundials, a vertical rod cast a shadow on a plane surface marked with numbers to indicate the time of day. This simple dial was inaccurate, however, because no provision had been made for the motion of the sun in a north-south direction with the changing seasons. The sundial in use today is a modification of this early instrument in which a rod tilted to correspond to the tilting of the earth's axis compensates for the north-south motion of the sun.

As soon as man began to extend his daily activities beyond the limits of daylight, he needed a new timepiece. Accordingly, some unknown inventor devised the water clock. Fundamentally, the action of water clocks depended upon the rate of flow of water through a small opening. Since water freezes, evaporates, and undergoes considerable expansion and contraction with changes in temperature, a water clock could not be extremely accurate. The sandglass was a variation of the water clock, and although it overcame some of the difficulties encountered in the latter, certain physical characteristics, such as lack of uniformity among the individual sand particles, prevented this instrument from reaching the desired standards of accuracy.

Other means of keeping track of time were tried locally throughout the world. Candles and tapers were used in some places because they burn at a fairly uniform speed. Since they were graduated, passage of time was measured by the amount of candle or taper consumed.

The early water clock furnished the inspiration which led to the development of mechanical clocks. The first variation was the use of a pulley or gear operated by a float that was raised as the water gradually entered a cylindrical receiving vessel in which the float rested. An hour hand attached to the pulley or gear pointed to numbers on a dial thus indicating the time. The next big improvement was the substitution of a weight for water as the driving mechanism. The weight clock was inaccurate until a way was found to regulate the lowering of the weight so that the hand of the clock would move over equal distances in equal times.

About 1583, Galileo, when only about 19 years of age, discovered the principle of the pendulum and laid plans for a pendulum

clock. The periodic swing of the pendulum provides the regular escapement needed in the lowering of the weights. The even, to-and-fro swinging of a lamp in a church is said to have inspired Galileo with the idea that resulted in his discovery. Although there is evidence that others before the time of Galileo had built clocks using the pendulum, it was he who paved the way for the invention of a pendulum clock essentially like those in use today. The substitution of steel springs for weights as the driving mechanism was an important later change. From 1700 until very recently, there has been little change in the basic principles of clockmaking.

The most recent development in the manufacture of timepieces is the electric clock. There are two different types of clocks which make use of the electric current. One type is simply an ordinary clock to which is attached an electric motor to keep it wound. The other type, constructed on an entirely different principle, is really a tiny electric motor whose motion is kept in step with that of the alternating current generators in the powerhouse. Nearly all power companies generate current which reverses its direction precisely 120 times a second. It is known as 60-cycle current. When purchasing a clock based on this principle, make sure that it has been made for current of the same number of cycles as that available in the house line. This type of clock will not function on direct current.

• THE STORY OF THE CALENDAR

If someone should ask you, "On what day of the week will the New Year begin?" you could find the correct answer by referring to the calendar. Since the calendar is a man-made device, it was not always possible to get the answer in this easy manner. Such a question was once meaningless because our remote ancestors had not yet recognized and defined the year or the smaller time units which we call the month and week. The development of the calendar has been a slow, gradual process dating from prehistoric times. It cannot correctly be said that any one person or any one nation invented it. Astronomers, mathematicians, priests, and great rulers have all had a part in bringing the calendar to its present form.

When early people felt the need for time units longer than the day, they again turned to the sky. They seem to have become aware of the monthly change in the shape of the moon about as

early as they noticed that day and night follow each other regularly. Observations over a period of time showed that the various shapes of the moon also followed each other in a definite sequence. It was quite natural for them to adopt the interval from one new moon to the next as their unit of time. Expressions such as, "He came back two moons ago," were very common among the primitive races. Sometimes they called the intervals "months." Lunar months are 29½ days long because the cycle of the moon's phases is completed once in this many days.

The year is another natural time unit. It is, of course, the interval required for the earth to complete one revolution about the sun. Astronomers call it the year of the seasons and define it in terms of the experiment they would perform to determine its exact length. To them it is the interval of time between two successive crossings of the sun over the celestial equator at vernal equinox. Each of these crossings, as we have already learned, marks the beginning of spring about March 21. Early people counted years by the succession of the seasons or by the occurrence of certain events. The coming of the warm days of summer, of the snows of winter, and of harvest time and the migrations of the birds in spring or fall have served in various localities as indications that another year had passed. Man's interest in the heavens led very early to his discovery that a constellation which had appeared in the east just before sunrise reappeared there again at an equal interval before sunrise just one year later. Some tribes even today watch the Pleiades, the little "seven sister" constellation, to find out when a new year has begun.

Difficulties arose when man tried to fit the days, months, and years into a single system for reckoning time. As we have seen, neither the solar year nor the lunar month contains an even number of days. Moreover, the lunar months do not fit evenly into the solar year; there are about twelve and one-third of these months in one solar year. The chief troubles of calendar-makers have come from this failure of the smaller units to fall evenly into the larger ones.

The Egyptians, it is believed, adopted a calendar based on the solar year more than six thousand years ago. Egyptian astronomers had decided upon 365 days as the length of the year from their timed observations of the apparent traveling of Sirius, the Dog Star, through its heavenly cycle. Their economic life had always been divided into the season when the Nile overflowed its banks, the season of seedtime, and the season of harvest. No doubt they

adopted the year as a convenient time unit because its span was just large enough to contain their three seasons. Since they found that it was impossible to divide the year into an even number of true moon months, they arbitrarily divided each season into four months of thirty days each. The five days left over did not belong to any month and were used as festival days with which to end each year.

Since the true solar year was really about one quarter of a day longer than the one adopted by the Egyptians, the Egyptian calendar contained an error which became correspondingly greater as the years passed. As a result, the dates which they had set aside as holidays and special occasions did not continue to fall at the same time each year with respect to the seasons but traveled slowly backward through the natural seasons during the many centuries when the calendar was used.

Later when the Babylonians, Greeks, and Romans found the months of the calendar slipping from their proper places in the seasons, they adopted various corrective measures. We, too, would likely be stirred to action if yearly dates began to shift with respect to the seasons, so that the Fourth of July, for example, promised in time to become a winter holiday. The correction usually took the form of an extra month or two added to the year whenever needed to restore the months to their proper places in the seasons.

In the days when Rome was a republic (509-49 B.C.), the calendar became a political football. The priests, whose office gave them the authority to decide how many months a given year should have, sometimes added a month when none was needed and sometimes failed to add one when they should have done so. In this way they prolonged or shortened the terms of public officials according to their own wishes and interests.

Superstition further complicated the job of the priests and calendar-makers. Because of the belief that even numbers bring bad luck, the twelve regular months had been changed so that seven of them now had twenty-nine days, four had thirty-one days, while February with twenty-eight days was the only one without the lucky odd number. The unintentional errors which were added to the wilful ones brought the Roman calendar to a state of rather hopeless confusion within a few hundred years.

After Julius Caesar became ruler of the Roman Empire, he decided to abolish the old calendar and replace it with a satisfactory one. The makers of the new calendar profited from a knowledge of the shortcomings of the early ones and, of course, had at

their command more recent astronomical data. They adopted the solar year as the basis for the "Julian" calendar, as it is now called. The Romans were more accurate than the Egyptians, whom they were imitating, because they recognized that the solar year is longer than 365 days by about one-fourth of a day. Since it is impractical to have the new year begin at odd hours of the day, the quarter days were taken care of by a leap year every fourth year with 366 days instead of the usual 365. Caesar and his advisers continued the practice of dividing the year into twelve months, but they paid no attention to the moon in determining the length of the month. To appease the superstitious Romans, they made half of the months "lucky" by giving them thirty-one days each, while the others contained thirty days each, except February, whose twenty-nine days became thirty in leap years when it inherited the extra day. The Julian calendar became effective in Rome on January 1, 46 B. C., and subsequently was widely adopted throughout the civilized world.

An interesting change was made in the Julian calendar during the reign of Augustus Caesar, who succeeded Julius Caesar as emperor. July had been named after Julius Caesar, and it was decided to honor his successor by changing the name of the next month to August. But this month had only thirty days, and a month with an even number of days could not possibly be worthy of the name of a Caesar. So February was robbed of a day, which was given to August. This change was not enough, however, because it was deemed unwise to have three successive months, July, August, and September, with thirty-one days, as they now would have had. To overcome this difficulty, the last day of September was given to October; at the same time the thirty-first day of November was given to December. This arrangement of days into months, as well as the names given to the months by the Romans, has remained unchanged to the present time.

In spite of the great care that had been exercised in the preparation of the Roman calendar, it failed to withstand the test of time. Again, the dates shifted from their places in the seasons, but more slowly, it is true, than ever before. In the sixteenth century, when the shift had amounted to ten days, Pope Gregory XIII decided to correct the error in the structure of the calendar and also to return the dates to their proper places in the seasons. He was anxious to make a change in the calendar because of the dislocation of certain church festivals, and he was able to effect the reform needed to solve the problem by virtue of the great author-

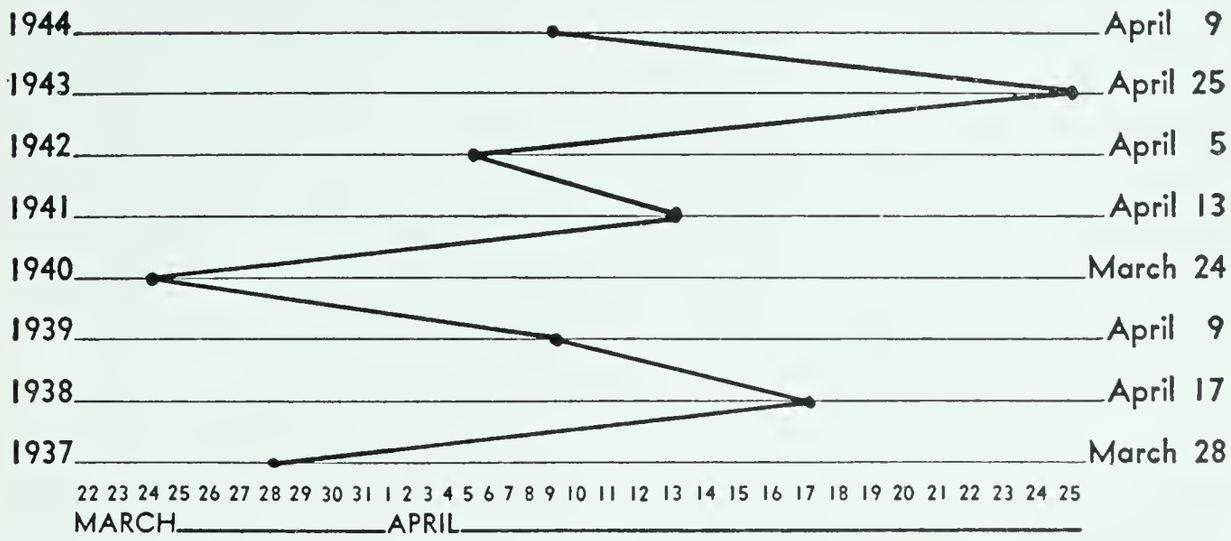
ity invested in him as the head of the Roman Catholic Church.

The length of the solar year used in the Julian calendar was not quite accurate, and it was known that this was the source of the slight variance in the calendar. The solar year, or year of the seasons, is 11 minutes and 14 seconds shorter than the year of 365¼ days used by Caesar. Rounding off the part-day period into a quarter day had, of course, suggested to the Romans the convenient device of making every fourth year a leap year to take care of this extra period. Whereas the dates had slipped backward in the seasons in previous calendars because the calendar year was too short, they now were going in the opposite direction because the calendar year was too long. This meant that leap years were coming too often. Pope Gregory commissioned an Italian astronomer to work out a plan for overcoming this difficulty. Hence came the scheme of leap years which we follow today. Any year whose number is evenly divisible by 4 but not by 100 is a leap year. In addition, any year whose number is evenly divisible by 4, 100, and 400 is also a leap year. Thus the year 1900 was not a leap year —1900 cannot be divided evenly by all three divisors, 4, 100, and 400; 1940 was a leap year—it can be divided by 4 but not by 100; the year 2000 will be a leap year because it is evenly divisible by 4, 100, and 400.

Pope Gregory decreed that the revised calendar should become effective in the fall of 1582 when the day following the Feast of St. Francis was to become October 15th, instead of October 5th. In this way, the error accumulated with regard to the seasons was eliminated at the same time that the new system was inaugurated. The Gregorian calendar did not become effective everywhere immediately. Great Britain, for example, did not adopt it until 170 years later; Greece not until 1923. Today it is used in all Christian nations.

You might wonder if these thousands of years of evolution have at last produced a calendar which is exactly in step with the march of the seasons. The answer is "no"; the average year of the Gregorian calendar is still twenty-six seconds longer than the year of the seasons. This error will not become appreciable until almost the year, 4000, when the calendar could be made extremely accurate by keeping as common years instead of leap years those years whose number can be divided evenly by 4,000. Perhaps, then, it may seem strange that there is considerable agitation at present for further calendar reform. The present movement for reform of the calendar arises, as we shall see, from a different reason than

THE ZIGZAG COURSE OF EASTER



Courtesy World Calendar Association

If the World calendar were adopted, Easter Sunday would always be the second Sunday in April—that is, April 8.

ever before. The League of Nations, our own National Education Association, and many other public bodies have seen fit to appoint committees of inquiry into calendar reform. Many plans have been considered and a few have received rather favorable consideration.

The present agitation for reform has sprung largely from the business world. Inconvenience arises because the weeks do not fit evenly into the month or year and because the months and quarterly periods of the year vary in length. Allowances for these inequalities must be made when firms compare the business of one month or one quarter with that of another. Employees working for a monthly salary receive less a day for their services during some months than during others. Since each year begins one or two days later in the week than the previous year did, New Year's Day and the other holidays shift through the days of the week as the years pass. In this respect, therefore, the calendar changes; this makes necessary yearly expenditures of large sums of money for printing new calendars.

The proposed plans involve changes in the grouping of the days within the span of the year, but no change in the length of the year itself. The excellence of the present calendar in this respect is universally recognized. One of the new plans would divide the year into thirteen months of twenty-eight days each. The extra day of common years and the two extra days of leap years would not be considered as part of any week or month and would very

likely be used as holidays. Another plan would divide the year into two equal halves of 182 days each and four equal quarters of ninety-one days each. Each quarter would be divided into three corresponding months, one having thirty-one days and the other two, thirty days each. The leftover day or days of the year would again be taken care of by declaring them holidays. The World Calendar, as this plan is called, is shown below. Many other arrangements for overcoming the difficulty of the present calendar have been offered, but these two seem to have received more favorable attention than others.

First Quarter							Second Quarter							Third Quarter							Fourth Quarter						
JANUARY							APRIL							JULY							OCTOBER						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14	8	9	10	11	12	13	14
15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28	22	23	24	25	26	27	28
29	30	31	..	..	..	..	29	30	31	..	..	..	..	29	30	31	..	..	..	..	29	30	31	..	..	..	..
FEBRUARY							MAY							AUGUST							NOVEMBER						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
..	..	..	..	1	2	3	4	..	..	..	..	1	2	3	4	..	..	..	1	2	3	4	..	..	..	1	2	3	4
5	6	7	8	9	10	11	5	6	7	8	9	10	11	5	6	7	8	9	10	11	5	6	7	8	9	10	11
12	13	14	15	16	17	18	12	13	14	15	16	17	18	12	13	14	15	16	17	18	12	13	14	15	16	17	18
19	20	21	22	23	24	25	19	20	21	22	23	24	25	19	20	21	22	23	24	25	19	20	21	22	23	24	25
26	27	28	29	30	..	..	26	27	28	29	30	..	..	26	27	28	29	30	..	..	26	27	28	29	30	..	..
MARCH							JUNE							SEPTEMBER							DECEMBER						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
..	..	..	..	..	..	1	2	..	..	..	..	..	1	2	..	..	..	..	..	1	2	..	..	..	..	..	1	2
3	4	5	6	7	8	9	3	4	5	6	7	8	9	3	4	5	6	7	8	9	3	4	5	6	7	8	9
10	11	12	13	14	15	16	10	11	12	13	14	15	16	10	11	12	13	14	15	16	10	11	12	13	14	15	16
17	18	19	20	21	22	23	17	18	19	20	21	22	23	17	18	19	20	21	22	23	17	18	19	20	21	22	23
24	25	26	27	28	29	30	24	25	26	27	28	29	30	24	25	26	27	28	29	30	24	25	26	27	28	29	30
													**														*

**LEAP-YEAR DAY, June L or 31, an extra Saturday, a WORLD HOLIDAY.

*YEAR-END DAY, December Y or 31, an extra Saturday, a WORLD HOLIDAY.

It would be foolish for one country to reform its calendar unless a majority of the more important nations of the world did likewise. If such reform is effected, it is certain that for the most part, the time-tested principles on which the present calendar is based will be retained.

The week merely satisfies the need for a time unit intermediary in length between the day and the month. Some early calendar-makers, like the Egyptians, made no provisions for such a unit because no need was felt for it. The length of the week was not determined by the recurrence of any astronomical event as was

true in the case of the day, the year, and, to some extent, the month. The number of days in the week might well have been some other convenient number besides seven. The selection of the number, seven, dates to ancient astrology. The "wanderers"

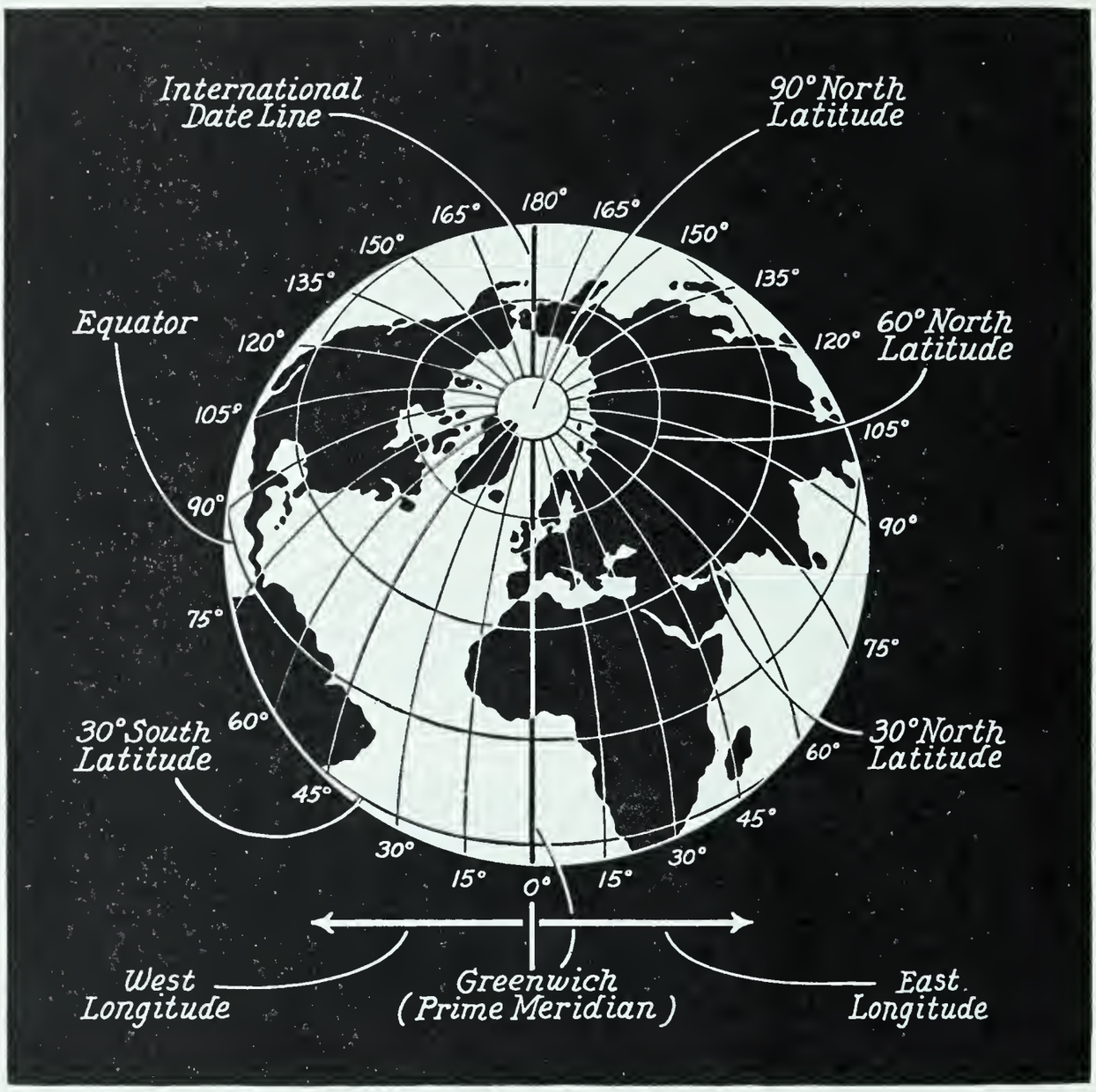
Heavenly body	Saxon name	Day of week
Sun	.....	Sunday
Moon	.....	Monday
Mars	Tiu	Tuesday
Mercury	Woden	Wednesday
Jupiter	Thor	Thursday
Venus	Frigg	Friday
Saturn	.....	Saturday

of the sky were regarded as gods, and a day of the week was named in honor of each. Had it been known that there are other planets, no doubt the length of our week would not be what it is today.

• LOCATING POSITIONS AND FINDING DIRECTIONS ON THE EARTH

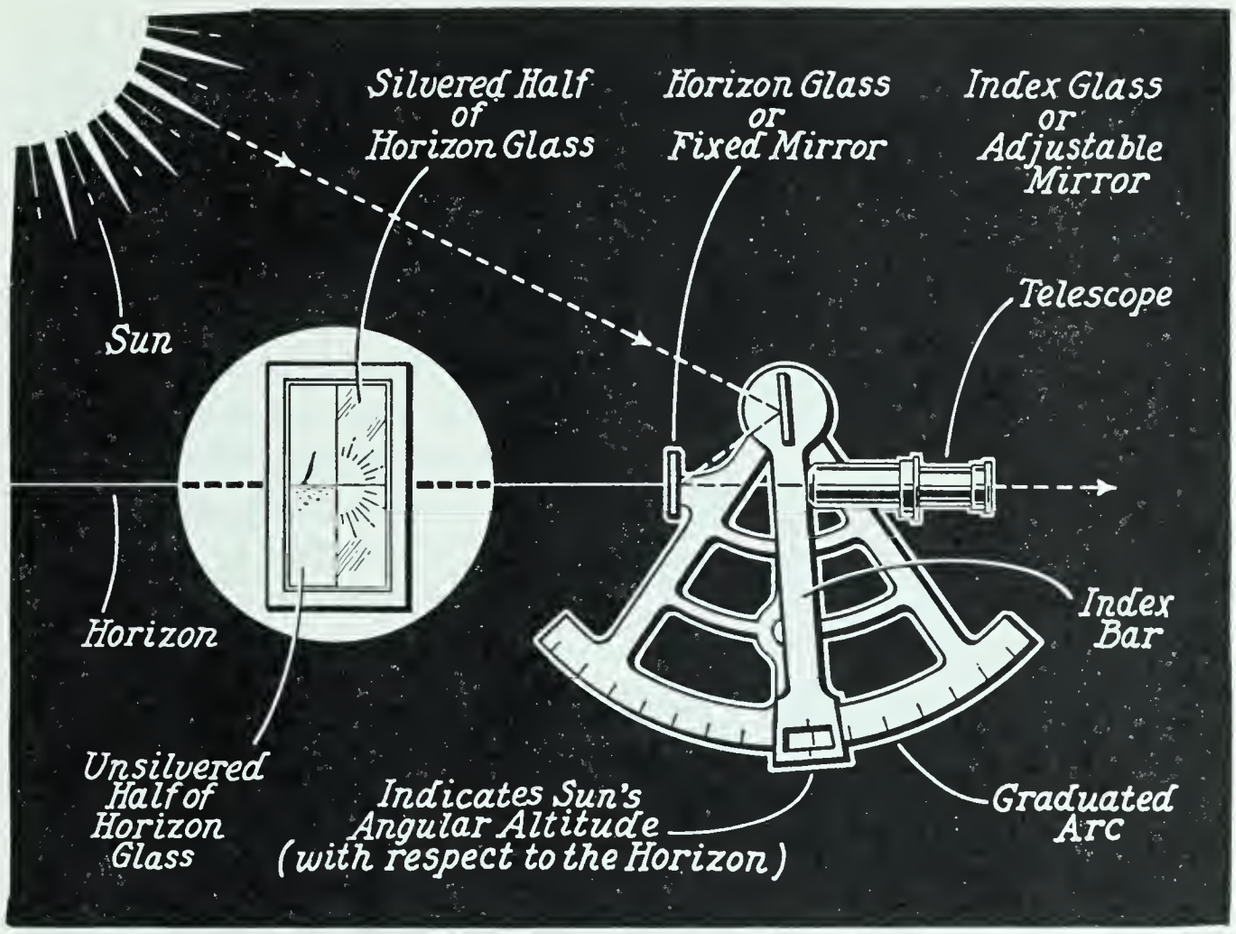
As soon as man began to sail the seas, he found himself more than ever in need of reliable methods of determining directions and locating positions on the spinning earth. Not until the compass had been invented, could man venture out of sight of land, confident that he could find his way back again. If his ship were lost or disabled at sea, he was at the mercy of fate as would-be rescuers searched at random for him. Even today, the radio would be of little help to a vessel disabled at sea unless the position could be reported in terms that would be intelligible to those receiving its call for help. To radio that you were in distress three hundred miles from New York City would not be of very much help to searching parties, because there are so many places on the ocean which are three hundred miles from New York City. The description of position in degrees of longitude and latitude, however, locates places very definitely for all who are acquainted with the system universally used in mapping the earth's surface.

Man has marked off the earth's surface with two sets of imaginary lines whose intersections enable him to locate positions or places. The curved lines running north and south from pole to pole are called meridians of longitude. The prime meridian, or meridian of zero longitude, passes through Greenwich, England.



To locate places and positions on the surface of the earth, man uses imaginary lines called parallels of latitude and meridians of longitude.

On the other side of the earth, it continues as the 180th degree meridian and follows very closely the international date line. If you traveled due east or west from the prime meridian, you would pass by other meridians until you arrived at the 180th degree meridian; you would then have half completed a trip around the world. If the journey had been made in a westward direction, you would have passed over all the meridians of west longitude and upon continuing you would begin to cross the meridians of east longitude. The numerical values of these meridians, which would represent degrees east of the prime meridian, would gradually decrease until you once more reached your starting point. Longitude, then, is the distance east or west of the prime meridian expressed in degrees.



This drawing shows the main parts of the sextant as well as the manner in which it is used.

The path taken in this imaginary journey around the earth would really be a parallel of latitude. The equator is the line of latitude which divides the earth in halves midway between the two poles. All circles drawn around the earth parallel to the equator are also parallels of latitude. Their distance north or south of the equator is also expressed in degrees. These circles, of course, decrease in circumference as the poles are approached, until finally the circle becomes a dot when the pole is reached.

Each place on the earth's surface is located at the intersection of a parallel of latitude and a meridian of longitude. If only one of these were given, it would merely be known that the place was located on a certain circle around the earth. But when the location of a place is given in terms of both latitude and longitude, one can turn to a map or globe of the earth on which the parallels and meridians are shown and readily locate the place. This is a very practical application of the rule learned in geometry, that the intersection of two lines locates a point. Just as the hour is divided into minutes and seconds to make time expressions more exact, the degree is divided into sixty parts called minutes, and



Courtesy *Los Angeles Times*

Science aids in the defense of America. This officer uses the sextant to "shoot" the sun or pole star, takes the correct time, and then consults the nautical almanac to determine his ship's latitude.

the minute into sixty parts called seconds. Thus an accurate location of New York City is stated as follows: 73 degrees, 57 minutes, and 30 seconds west longitude; 40 degrees, 48 minutes, and 35 seconds north latitude.

From the commercial viewpoint, the most important contribution of astronomy has been the method of determining latitude and longitude. An accurate determination of the exact position of a ship at sea, together with a knowledge of the latitude and longitude of the port toward which it is proceeding, enables the navigator to decide upon the direction in which the ship must be steered to reach its destination. When clouds do not interfere, mariners periodically make sure that ocean currents or other causes have not deflected the ship from the plotted course. During cloudy periods when the data necessary for checking latitude and longitude cannot be obtained from the heavens, mariners become more solely dependent upon the compass and lack the positive assurance that a determination of latitude and longitude bring.

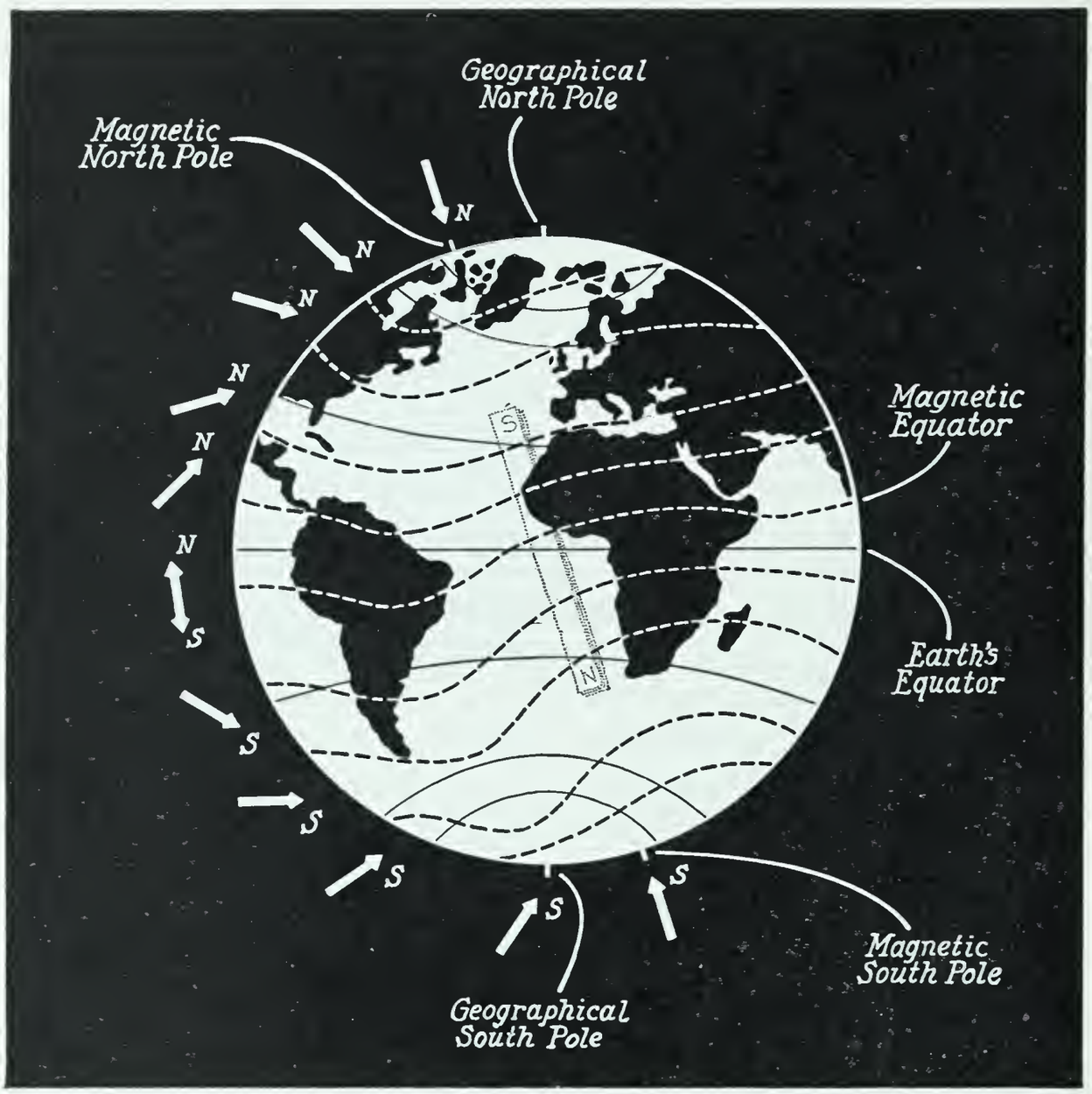
The sextant is the instrument which mariners use to determine latitude. It was invented about 1730. The essential parts of the sextant are shown in the drawing on page 271. In use, the mariner holds the sextant vertically in such a position that, when he looks through the small telescope, he sees the horizon through the unsilvered half of the horizon glass. He moves the index bar until the image of the sun is reflected from the index glass into the silvered half of the horizon glass and is exactly in line with the horizon. The reading on the graduated arc is the sun's angular height above the horizon for that instant. This is called "shooting the sun" and is done at noon, ship's time, because the sun is then at the zenith. After making necessary corrections in the reading and by con-

sulting astronomical tables which give the sun's distance north or south of the equator for that date, the mariner can calculate the latitude of the ship by comparing the observed altitude of the sun with the sun's position as given in the astronomical tables. If the mariner shoots the pole star with his sextant, he obtains the latitude directly, because *the angular attitude of the pole star is the same as the latitude of the place.*

Longitude differences are calculated from time differences. As we have already seen, local solar time varies from place to place as we go eastward or westward. The maximum time difference is, of course, a full day or twenty-four hours; the maximum longitude difference is 360°. Then, a difference of one hour between two places indicates a difference of one twenty-fourth of 360°, or 15°, of longitude. Since, by common consent, the meridian passing through Greenwich is the meridian of zero longitude, the longitude of any place can be calculated if the difference between its local solar time and that of Greenwich is known. Each difference of one hour means a difference of 15° in longitude. A very accurate clock, called a chronometer, is carried by the ship to keep track of Greenwich time. Formerly, ships "rated" their chronometers before leaving port by comparing them on successive days with telegraphic signals indicating correct Greenwich time; now, of course, they may receive Greenwich time by radio even while at sea. The ship's local solar time can be obtained by observation of the sun—it is local noon when the sun is at the zenith. The difference between ship time and Greenwich time is changed to degrees of longitude as already described.

Thus we see that the determination of the parallel of latitude and the meridian of longitude which pass through a given place enables one to turn to a map or globe and see exactly where this place lies in relation to all other points on the earth's surface. Is it not curious that man has found it necessary to focus his telescope on heavenly bodies millions of miles away in order that he may adequately make adjustments to the problems which require an exact knowledge of his location here on the earth?

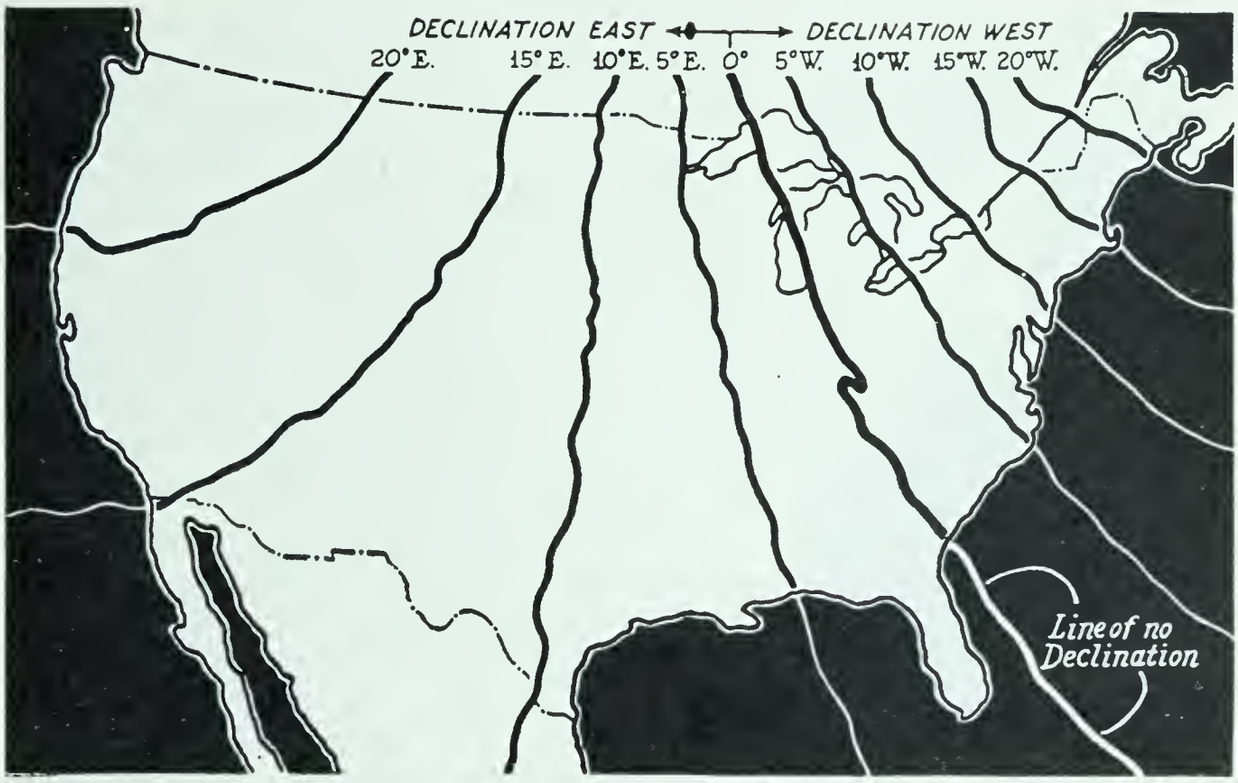
Any magnetized bar or needle suspended so that it can swing freely in a horizontal plane is a compass. Although the Chinese discovered this useful instrument more than three thousand years ago, it did not come into use in Europe until the twelfth century A. D. Iron, cobalt, and nickel are single substances which can be magnetized, but mixtures of metals, or alloys, are made which possess even greater capacity for magnetism. The attraction of



A magnetic needle suspended on a horizontal axis so that it can swing in a vertical plane stands straight up and down at either pole and rests horizontally at the magnetic equator. In between these places it dips somewhere between 0 and 90 degrees. Knowledge of the dip enables one to turn to reference tables and find his approximate distance north or south of the equator.

magnets appears to be concentrated near the two ends, and these centers of magnetism are called poles.

The earth iself acts as a great magnet and its poles are called the North and South Magnetic Poles. Simple experimentation with two compasses shows that the two poles of a compass are not alike. Unlike poles attract each other, and like poles repel each other. Thus a compass needle swings until each of its poles is as near as possible to the pole of the earth which is opposite in magnetic nature. The pole of a compass which points toward the



In what way does declination represent error in the compass reading with reference to geographical north? What is the approximate error for your locality?

earth's North Magnetic Pole is called the north pole of the compass. It is really the north-seeking pole. In a similar manner the south pole of the compass is named.

Since the geographic poles and the magnetic poles of the earth do not lie at exactly the same place, the north-seeking end of the compass usually points either east or west of the north geographic pole. Some believe that Columbus was the first to observe that the compass does not point to the true north and that the amount of error varies from place to place. When the east or west *declination* is known for the place where the compass is used, an allowance can be made for it and direction can be obtained very accurately by means of the magnetic compass.

Difficulties are encountered in the use of the magnetic compass on modern vessels because of the influence of the iron and steel used in the construction of the ships. For this reason another compass has been more recently developed which does not depend on magnetism. It is really an outgrowth of the gyroscopic top which is commonly seen used as a toy. The action of the gyroscope is not difficult to understand if one first examines a gyroscope very carefully to see how it is made. A typical gyroscope is really a spinning wheel with its shaft so mounted in supporting rings



Courtesy Sperry Gyroscope Company, Inc.

The gyrocompass is a complicated mechanism built to overcome the defects of the simple magnetic compass.

that its axis is free to assume any direction in space. When the wheel is rapidly spinning, it resists any attempt to turn its axis out of the plane in which it is already spinning. The gyroscope can be carried about on its support in any direction, but the axis of the spinning wheel will not move out of its original direction. Its mountings make this possible, since they can turn without it being necessary for the axis of the wheel to turn. Thus if a gyroscope is set with the axis of its spinning wheel in an east-west direction, this axis will remain in this original direction as long as the wheel is kept spinning.

An ingenious addition to the gyroscope causes its axis to turn until it assumes a true north-south direction. This is a semicircular tube of liquid which is strapped to the frame in which the wheel is suspended. As the rotation of the earth causes this frame to tilt, the height of liquid in the two arms of the semicircular tube becomes different as liquid flows from the higher to the lower arm. Thus the two sides become unbalanced in weight, and gravity exerts a force on the gyroscope which causes it to turn about the vertical axis until the axis of the spinning wheel points due north and south. Since the level of the liquid in the two sides is the same in this position, there is no unbalanced force to cause further turning in the mountings of the instrument. The modified gyroscope thus indicates the true north-south direction, no matter where it happens to point while its wheel is being set in motion. Both of the disadvantages of the magnetic compass—(1) that it points to the magnetic pole rather than the true north; (2) that it is affected by magnetic substances—are overcome in the *gyrocompass,* as this instrument is called.

As you have just seen, man has adjusted to the problem of keeping track of direction on the earth by taking advantage of the earth's magnetism in the magnetic compass and of its spin and its force of gravity in the gyrocompass. The gyrocompass is the only machine to make use of the spinning motion of the earth.

Exercises for Problem Study and Review

1. Describe the clock in the sky. Where is the axis of the hour hand? Where is the outer end of the hour hand. What makes the hour hand go around the sky?

2. What is a celestial meridian? How does the astronomer locate a fixed point on the circumference of the clock in the sky?

3. Why is sidereal time undesirable for everyday use? Why does the length of the solar day vary throughout the year?

4. When it is noon by local solar time at one locality on a certain meridian, what time is it (1) due north? (2) Due south? (3) At any point east of there? (4) At any point west? How would such variation be an inconvenience to railroads and travelers?

5. What steps were taken by the United States government in 1883 to eliminate the inconvenience mentioned in Question 4? How many time belts are there in the United States now? How far apart are the meridians marking their approximate centers? Why was this number of degrees chosen?

6. Into how many time belts has the surface of the earth been divided? What does the traveler do to his watch when going eastward from one time belt to another? When going westward?

7. If a traveler arrives at the international date line at 6 P.M. on Wednesday, what time of what day is it when he crosses this meridian if he is going westward? If he is going eastward?

8. When and where is each new day born? Which way does it travel around the earth? How fast does it travel? For what length of time is each day somewhere on the earth? At any particular place?

9. Name some early types of devices used by man to keep track of time, and point out the disadvantages of each.

10. To whom is credit given for the discovery of the principle of the pendulum? Why was this discovery an important contribution to the solution of the problem of keeping track of time?

11. How did the ancients use the moon as a timekeeper? The seasons? What difficulty arose when they tried to combine days, months, and years into a single system for reckoning time?

12. How many seasons, months, and days were included in the calendar adopted by the ancient Egyptians? Why was their calendar in error? What was the result of this error?

13. How was the calendar manipulated by the politicians of ancient Rome? What reforms were instituted by Julius Caesar? How did superstition influence the new calendar? How did Augustus Caesar alter the calendar during his reign?

14. What impelled Pope Gregory XIII to revise the calendar again? What revisions were worked out? What years are leap years? Is the Gregorian calendar perfectly accurate?

15. What calendar is in use today? Why is further calendar reform being sought by some groups? What general plans are proposed?

16. What two sets of imaginary lines are used in locating places on the earth? Where is the zero, or prime, meridian? What meridian is directly opposite on the other side of the earth? Where is the parallel of zero latitude? Where is 90° north latitude? Where is 90° south latitude?

17. State the rule in astronomy giving the relationship between the altitude of the pole star and the latitude.

18. What is the basis of calculating longitude differences? What is a chronometer? How does a ship at sea determine its own local solar time?

19. What disadvantages of the magnetic compass are overcome by the gyrocompass? How?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. Imagine that you are standing exactly on the north pole of the earth. (1) In what directions could you point? (2) Where would the north star be located? (3) Which stars would rise and set? (4) How fast would you be rotating?

2. Would you get more meat a pound (as measured with a spring balance) in Portland, Maine, or in Miami, Florida? Give two reasons for your answer.

3. Explain with the aid of a diagram how Venus goes through the same phases as does the moon. Why is it at times a "morning star" and at other times an "evening star"?

4. The axis of Mars is inclined 23½° to the plane of its orbit. How would you expect the Martian seasons to compare with those on earth?

5. Explain with the aid of a diagram why the period from one new moon to the next is a little more than two days longer than the time that would be required for the moon to go once around a stationary earth.

6. How could you calculate the diameters of sunspots from a photograph of the sun's disk which showed several of them? Try out your suggestions.

7. Imagine you are standing at some point on the equator. (1) Which stars would rise and set? (2) Where would the North Star be? (3) What would be your latitude?

8. What would be the advantage of applying the method of parallax to determine the moon's distance by sighting from two remote stations on the same meridian, rather than the same parallel?

9. With the aid of a diagram, explain why the solar day is four minutes longer than the sidereal day.

10. When it is 9 A.M. in New York, what time is it in (1) Atlanta? (2) Chicago? (3) Salt Lake City? (4) Los Angeles? (5) London? (6) Moscow? (7) Tokio?

11. What is the longitude and latitude of the place where you are?

12. What do you consider the greatest contribution of astronomy to mankind? Defend your choice.

13. In what ways does our present calendar show the influence of (1) astrology? (2) Superstition? (3) Astronomy? (4) Politics? (5) Religion?

14. How has the study of this unit helped to clarify your understanding of the scientific method?

15. How has the study of this unit changed your conception of the nature and extent of the universe?

16. What differences would be observed if we could view the sky from an earth having no atmosphere?

17. If a heavy steel ball is dropped from a west window of a high tower having vertical sides, it should strike the earth at a greater distance from the tower than it started, because the earth rotates from west to east. Evaluate this statement. How do you think the ball would fall?

18. If a star rises at 10 P.M. tonight, at what time will it rise (1) tomorrow night? (2) One month later? (3) One year from now?

19. How can you tell a planet from a star? How could you identify the planets visible to the unaided eye if you saw one or more of them in the sky?

20. As viewed from the moon, how often would the sun rise and set? The earth? The stars?

UNIT WORD LIST

centrifugal force
rotation
revolution
ecliptic
vernal equinox
autumnal equinox
summer solstice
winter solstice
celestial equator
ellipse
Ptolemaic theory
Copernican theory
gravity
satellite
planet
asteroid
comet
thermocouple
light-year
parallax
nebula
galaxy
celestial pole
celestial meridian
meridian
parallel
sidereal time
local solar time
standard time
international date line
prime meridian
Roman calendar
Gregorian calendar
sextant

meteor
meteorite
neap tide
spring tide
constellation
spectroscope
latitude
longitude
chronometer
magnetic declination
gyrocompass
eclipse

INTERESTING THINGS TO DO

1. Visit a projection planetarium, if possible. Describe it to the class.

2. Write an account of an imaginary trip to the planets, Mars and Jupiter.

3. Learn to point out in the present night sky (1) five constellations or star groups; (2) five bright stars and identify them by name; (3) as many planets as possible.

4. Assume that you leave the sun today in a rocket ship capable of a speed of ten thousand miles an hour and that you could travel in a straight line to all of the following places: (1) each of the planets; (2) the nearest star; (3) the nearest galaxy beyond our own. Prepare a time table to show when you would arrive at each.

5. Prepare a series of charts showing the more common constellations.

6. Prepare a group of photographs of the sky showing (1) star trails; (2) a continuous exposure of the moon for about one hour; (3) a series of three or four exposures of the moon (on the same negative) at hourly intervals without moving the camera; (4) the phases of the moon.

7. Prepare a report summarizing the contributions of eminent scientists to our knowledge of the sky, such as Copernicus; Kepler; Galileo; Newton; Herschel; Tycho Brahe; and Lowell.

8. Observe the rising of the moon for several successive nights from the same vantage point. Record the exact time of each rising and tell how much later the moon rises from night to night. Does the moon rise from the same point on the horizon each night? Give the explanation for each of these observations.

9. Make a collection of all the articles and pictures relating to the sky that are published during one month in the newspapers and magazines you receive in your home.

10. Make a series of drawings to show how various astronomical instruments are constructed. Explain to the class how each one works.

11. Make a yearly calendar for each of the two leading proposals for calendar reform, and figure out the date in each one corresponding to each date in our present calendar. Find out for each calendar the date of (1) your birthday; (2) Independence Day; (3) Washington's

birthday; (4) Columbus Day; (5) national election day; (6) Christmas. Tell the date in each new calendar on which each of the following would occur: (1) vernal equinox; (2) summer solstice; (3) autumnal equinox; (4) winter solstice.

12. Prepare a collection or display to show that astrological beliefs are widespread even today.

13. Make a display to illustrate the comparative sizes of the planets, using marbles, balls, or inflated toy balloons of appropriate size to represent the planets.

14. Consult the mathematics teacher in your school and find out how, by the use of principles of geometry, you can determine your latitude from an observation of the altitude of the sun at local noon by means of the sextant.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. The Foucalt pendulum.
2. Rockets and the possibilities of applying this principle to interplanetary travel.
3. Plans for calendar reform.
4. The story of the calendar.
5. The story of how man has kept track of time.
6. Theories as to the origin of the solar system.
7. Sunspots and their effects on the earth.
8. How standard time is obtained from the sky.
9. The earth-inductor compass.
10. The northern lights.
11. Famous telescopes and discoveries made with them.

INTERESTING BOOKS TO READ

Baker, Robert H., *An Introduction to Astronomy.* D. Van Nostrand Company, New York, 1935. A standard textbook. Clearly and interestingly written.

Baker, Robert H., *Introducing the Constellations.* The Viking Press, New York, 1937. Stories of the constellations well told and beautifully illustrated.

Baker, Robert H., *When the Stars Come Out.* The Viking Press, New York, 1937. Descriptive accounts of the heavenly bodies. Extremely interesting and beautifully illustrated.

Fisher, Clyde, *Exploring the Heavens.* Thomas Y. Crowell and Company, New York, 1937. An intensely interesting account of legend, theory, and fact about the heavenly bodies. There are many fine full-page illustrations.

White, W. B., *Seeing Stars.* Harter Publishing Company, Cleveland, 1935. A small but useful book. Several excellent illustrations. Can

be obtained in most ten-cent stores. It's a bargain.

Wilson, P. W., *The Romance of the Calendar.* W. W. Norton and Company, New York, 1937. Recognized as the best book on this subject. Time-keeping devices are traced from antiquity. The international and world calendars are discussed.

COAST COUNTS LOSS IN FREAK WEATHER

Damage to Crops Is Figured in Millions of Dollars, With Dates Hardest Hit

SOME CITRUS MEN GAINED

Saved Usual Irrigation Bills in Storm That Broke Heat Wave —Part of Jetty Gone

'Smog' Hits Radio City, Blackening Passers-By

Strollers in the vicinity of Radio City ran hurriedly for cover last night when one of New York's freakish "smog" storms descended on the area bounded by Fifth and Lexington Avenues and Forty-ninth and Fifty-fourth Streets. "Smog," as defined by the Weather Bureau, is composed of fine particles of dust that become moistened and descend in localized areas.

Cold Winter Predicted

Rushville Prophet Bases Forecast on Study of Equinoctial Winds

Building Shows Seasonal Drop In November

Local Construction $8,230,115, Against $9,899,727 Year Ago

WEATHER 'SIGNS' GAIN POPULARITY

WASHINGTON, Dec. 20.—With daily maps and forecasts by

Drought Hits Farmers Hard

Water Is Trucked for Cattle and Dust Piles Deep.

Rain Bogs Nazi Planes in Libya, Help to British

Newsman With B. E. F. Tells of Little Air Opposition in Desert

UNIT FOUR WEATHER AND CLIMATE

WARN ICE ON PARK LAGOON IS NOT SAFE

Winter sports fans and children

MONDAY SETS HEAT RECORD FOR 9 YEARS

Protect Fire Extinguishers Against Cold

Warning Is Given Today by

21 KILLED, 500 HURT BY GALE IN GEORGIA

Homes and Business Buildings Leveled in Dawn Storm— Loss at 5 to 10 Millions

Blanket of Fog Covers Nation

Up from the deep south, thru the Ohio valley, and on over the eastern states, a dense fog rolled today, crippling air, land and water travel. Its blanket was 1,000 or more feet thick; its mixture was peasoup—tagged by the U. S. weather bureau the densest fog in years.

Only a few fatal accidents were reported.

Not a plane had moved out from New York city's La Guardia airport since before midnight last night. In the metropolis' great harbor, ships remained still; at 8 a. m. (EST) the coast guard reported that visibility at the Narrows was only 10 yards. An hour later a welcome

New St. Louis Smoke Law Cuts Fog by 71 Per Cent

ST. LOUIS, March 3—The testing period of the smoke elimination ordinance ended tonight with

Winter Wheat Outlook Bright

Washington, Dec. 19.—(UP)—The Agriculture Department said today that the condition of winter wheat Dec. 1 indicated a 1942 yield of 630,910,000 bushels.

Imagine—Ski Council Hopes It Won't Snow

Spring Defies A Bronx Cheer

New York, Dec. 3.—Spring flowers are blooming in the Bronx. The New York Botanical Gardens, startled at this unusual situation, plan a spring flower exhibit over the weekend. In bloom are such



Unit Four

WEATHER AND CLIMATE

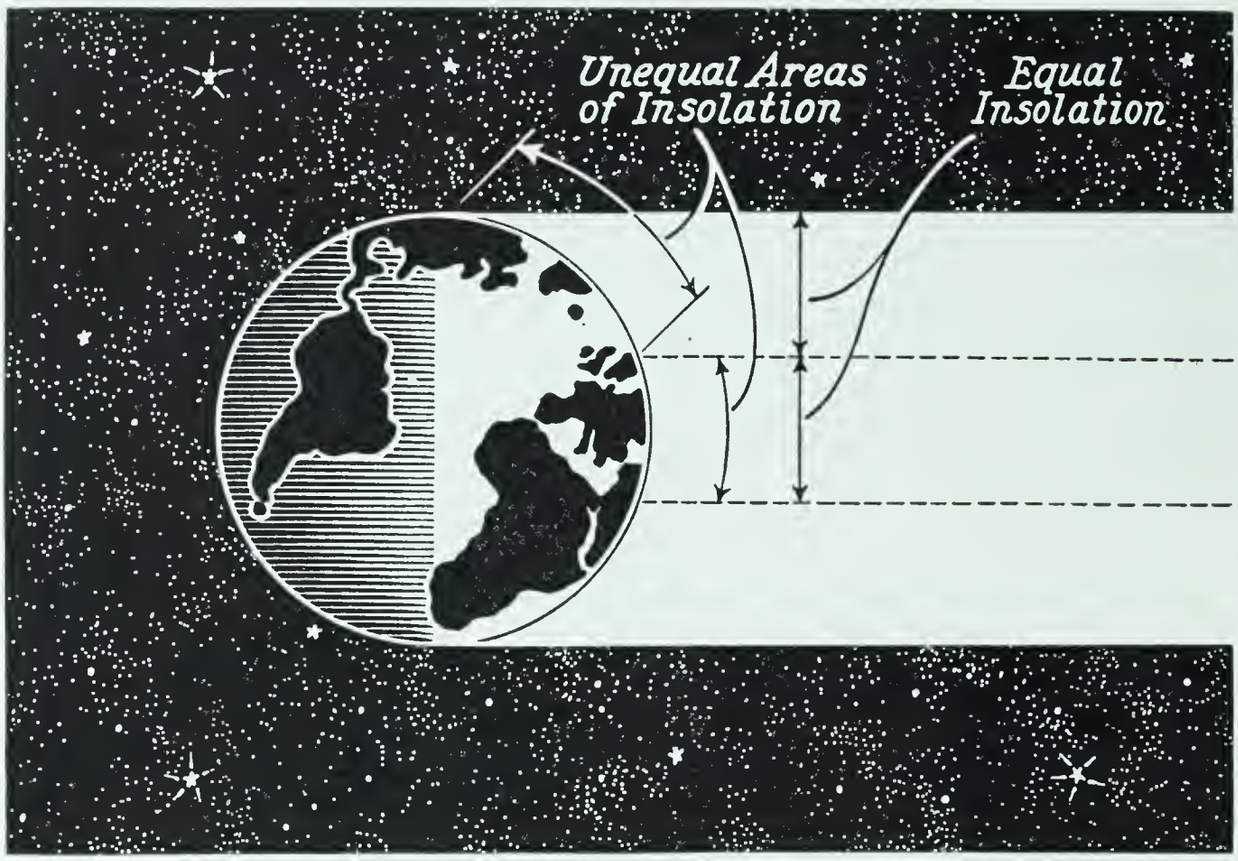
Let us consider the weather. It is such a frequent topic of conversation that we really should be informed on the subject. But more important than this, weather and climate have a great influence on our lives and our activities. How we dress, the cost and quality of what we eat, the occupations at which we work, the recreations in which we indulge, the amount of time we spend indoors or out—these all depend to greater or lesser degree on weather and climate.

The general tempo of our lives and the type of civilization we have are likewise governed largely by weather and climate. Frequent weather and seasonal changes seem most stimulating to man's energies and ambitions, and the most progressive civilizations are found in the temperate zones of the earth. In the equatorial regions and in the frozen North, progress has been very slow, chiefly because prolonged heat and cold are alike harmful to man's aspirations. In one case, the persistently hot and often muggy climate stifles ambition; in the other case, providing the necessities for existence leaves little time or energy to seek higher achievements.

Mark Twain once humorously observed, "Everybody talks about the weather, but nobody does anything about it." True, man cannot stop the wind or make it rain whenever he desires, but we shall discover in this unit that he, far from being indifferent to the weather, has achieved considerable success in his efforts to "do something about it." Our first step is to gain some knowledge of the principles and generalizations upon which our understanding of the nature of weather is based. These generalizations make possible the predictions we so highly desire. Prediction in turn makes it possible for us to adjust our activities more adequately through intelligent planning.

Desirable as it might be, it is, of course, impossible for man to control directly those gigantic natural forces that produce weather as we know it. On a smaller scale and within confined regions, we have achieved considerable success in controlling the atmosphere in which we live, as witnessed by the development of air conditioning. This, indeed, is "weather made to order."

Photo courtesy U. S. Weather Bureau



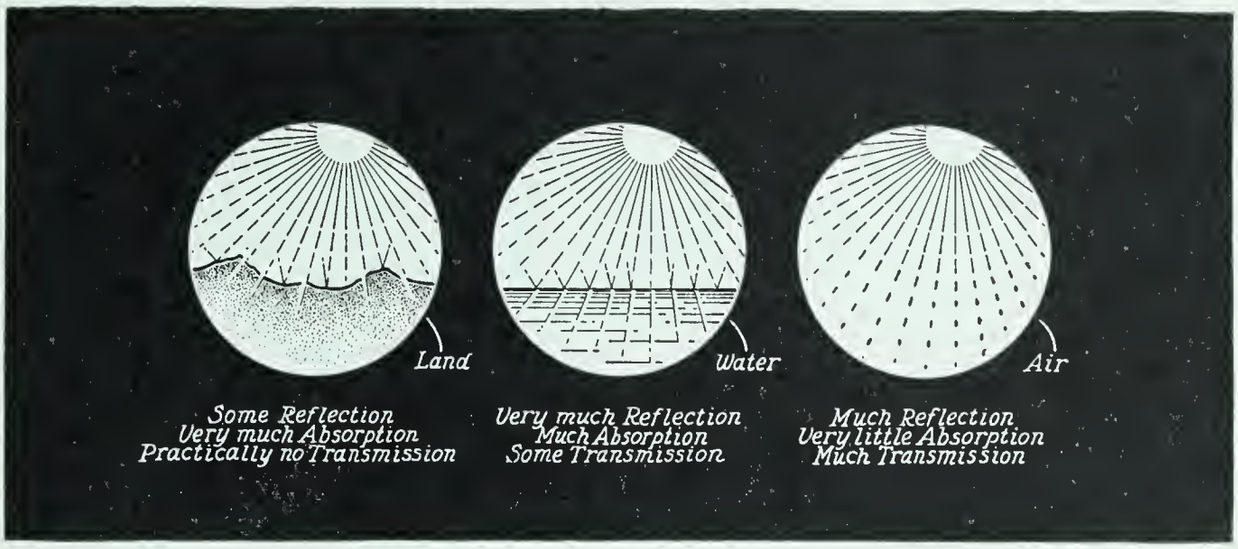
The heating effect of the sun's rays decreases as they spread over larger areas.

Problem 1: What produces the weather?

We live at the bottom of an ocean of air which extends outward from the earth and gradually thins into the vast emptiness of space, becoming of inappreciable density at a height of probably 150 or 200 miles. By means of balloons equipped with automatic recording instruments and sent up without men, as well as by man's own explorations of the upper atmosphere, it has definitely been established that this ocean of air is divided rather sharply into zones. At an altitude of 6 or 7 miles (about 35,000 feet) above the earth's surface, the temperature becomes nearly uniform at about —70° F.; there are no clouds. The zone above this level is the *stratosphere*. Below it is the *troposphere,* in which occur all the things that make up our weather—such as clouds, winds, vertical air currents, storms, fog, rain, snow, and temperature changes.

• THE SUN AND THE SEASONS

Once more we must turn to a distant member of the universe for a better understanding of the planet on which we live. As we

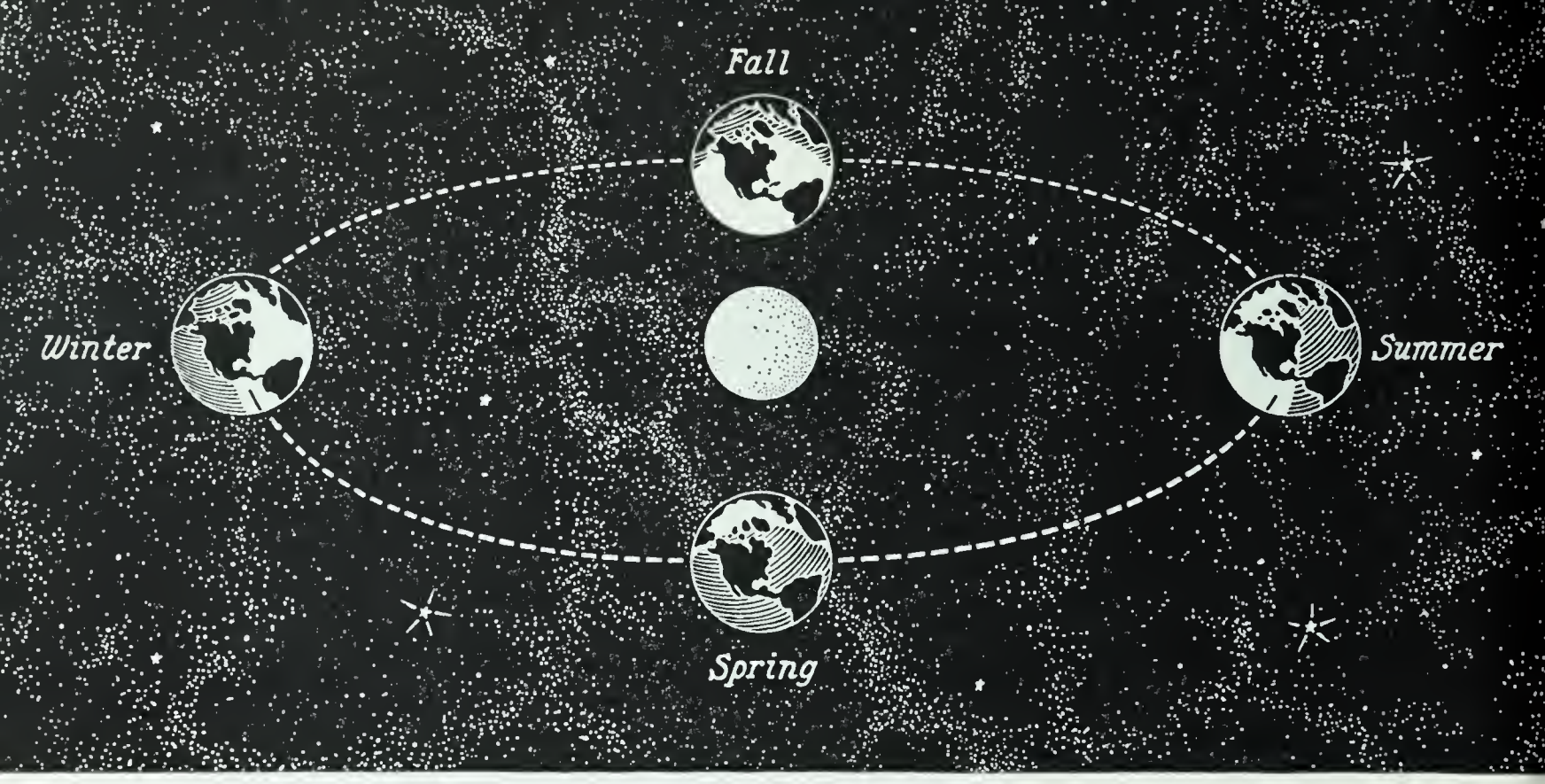


What becomes of insolation?

have seen previously, our determinations of longitude, latitude, time, and the calendar resulted from studies of the sky. Now we learn that the sun furnishes the energy responsible for those atmospheric changes which we sum up as *weather*. The sun stands first in importance as a cause of weather.

The heating effect of the sun depends upon the angle at which its rays strike the earth. The parallel rays of the sun strike the earth's surface at various angles which are determined by the height of the sun in the sky and by the curvature of the earth where the rays strike. When rays of light strike the earth at right angles—as when the sun is directly overhead—they cover the smallest surface area and pass through the least air on the way. When the sun is lower in the sky, the rays are more slanting; they therefore spread out over more area when they strike the earth, and a larger part is lost on the way through the atmosphere. Since light rays furnish a definite amount of sun energy, the *intensity* of the heat into which it is transformed decreases as the light spreads over more and more surface area.

Thus the gradual change in the angle of the sun's rays explains why the sun delivers different amounts of heat to the same locality at different hours of the day. Likewise, the difference in the average angle which these rays make in regions of different latitude accounts for the gradual drop in temperature as either pole is approached from the equator. The sun's rays are most nearly perpendicular to the earth at the equator. Therefore the hottest climates are found in that region. Furthermore a gradual shift in the angle of the sun's rays at any one place helps produce the



Seasons are caused by the tilt of the earth to the plane of its orbit.

general temperature levels which we associate with the seasons of the year.

The heating effect of the sun also depends upon wnat nappens to the rays when they strike the earth. When insolation (sun energy) is received, three things happen to it: it is partly reflected, partly absorbed, and partly transmitted. The extent to which each of these occurs depends upon the nature of the material which the rays strike, and only absorption results in an increase in temperature. Air, water, and land are heated unequally because of variations in their ability to absorb, reflect, and transmit the sun's rays, as shown by the tabulation below. A large part of the radiant energy on its way through the air is scattered in all directions by the air molecules. Much of this goes directly out to space again; the part that is scattered down to the surface causes the blue color of the sky.

DISPOSAL OF SUN ENERGY

Method	By air	By water	By land
Reflection	Large	Very much	Some
Absorption	Very little	Large	Very much
Transmission	Large	Some	Practically none

At this time it is advisable to recall three principles learned in our previous study of heat.

(1) Heat tends to "run downhill" passing only from hotter bodies to colder bodies or from regions of higher temperatures to regions of lower temperatures.

(2) Dark, rough surfaces are good absorbers and poor reflectors



The apparent daily path of the sun across the sky varies from season to season. What is the cause of the north-and-south motion of the sun? How does the heating effect of the sun's rays change as a result of this motion?

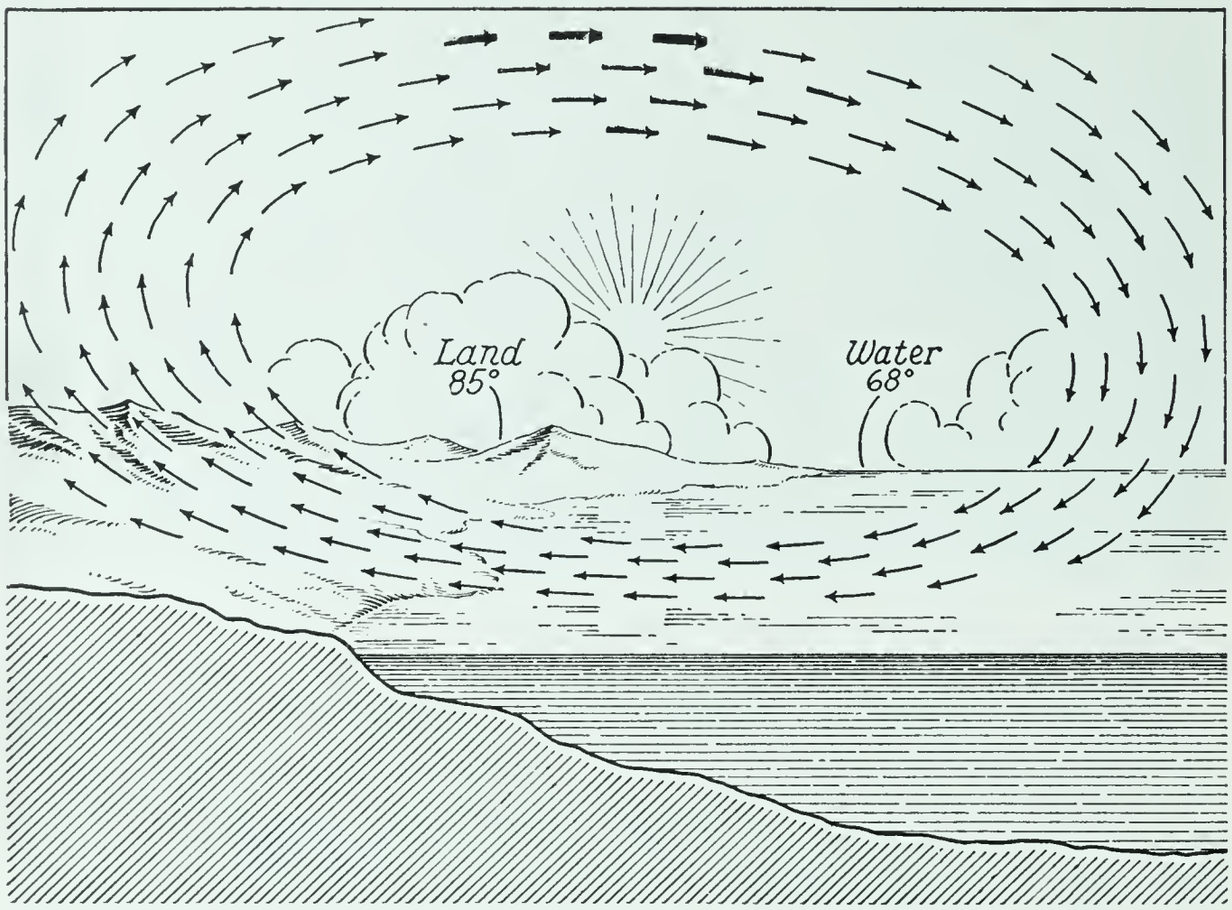
of heat, while bright, smooth surfaces are good reflectors and poor absorbers.

(3) Good absorbers of heat are also good radiators of heat.

Seasons result from the leaning earth. As the earth rotates about the sun, its axis is not "straight up and down"; instead, the earth is tilted approximately 23½° to the plane of its orbit. If the earth's axis were perpendicular to its orbit, days and nights would always be of equal length all over the earth. Study of the positions of the sun and inclined earth during the four seasons makes clear why daylight lasts for the longest time on summer days and for the shortest time during the days of the winter. The length of time during which the sun's energy is absorbed each day and the angle at which the rays strike combine to determine the general temperature levels of the seasons. Because daylight lasts longest in summer and because the sun's rays are then most direct, summer is the warmest season in spite of the fact that winter in the northern hemisphere is the season when the earth is nearest to the sun.

• AIR IN MOTION

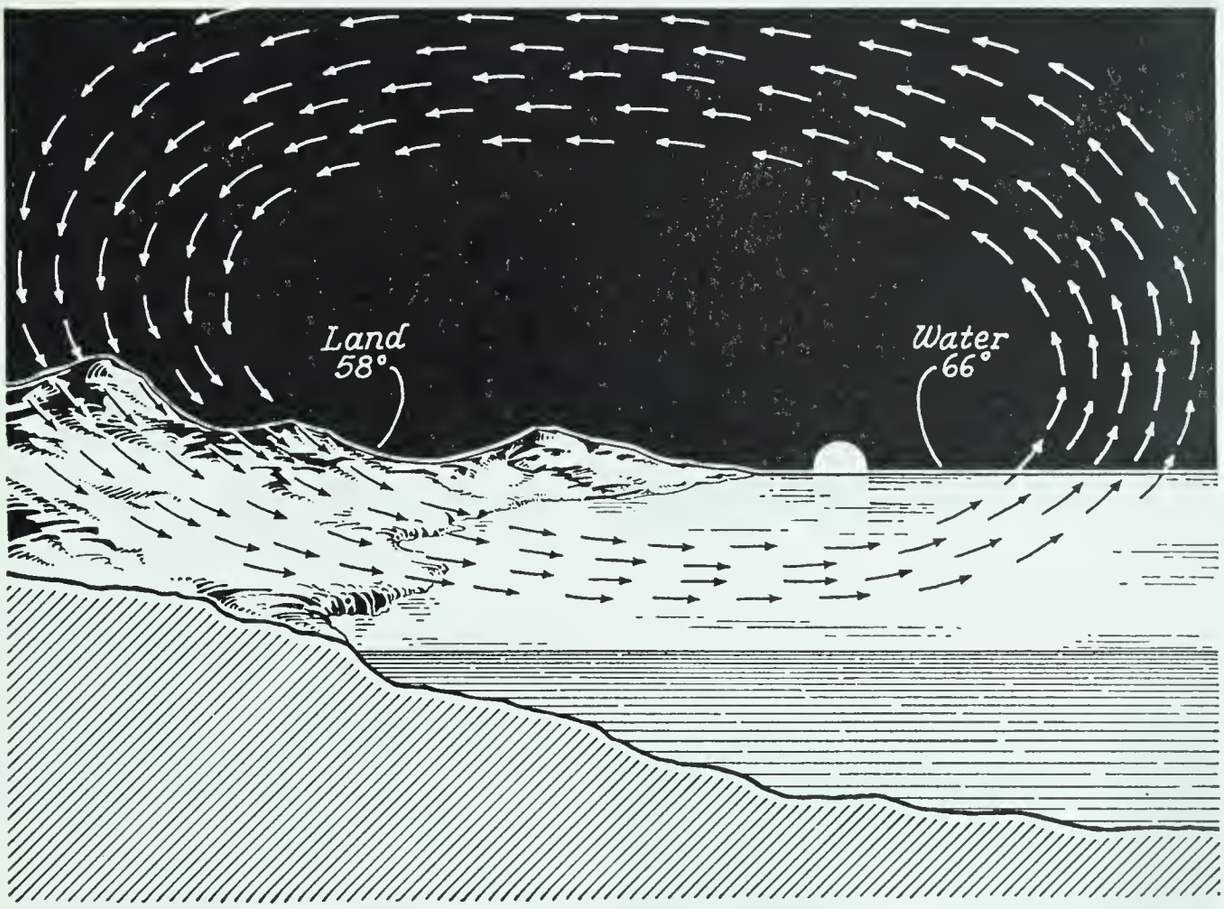
Winds are caused by unequal heating of the air. Air is warmed very little by the rays of the sun which pass through it, but the



The explanation for land-and-sea breezes lies in the fact that land both heats and cools more rapidly than water. What causes the direction of the breeze in the above drawing?

lower layers of air rapidly come to the same temperature as the land or water which they touch. The air loses heat to the earth, or the earth heats the air, depending upon which is originally at the higher temperature. The expansion of air as its temperature rises decreases its weight per cubic foot and it becomes light. Heavy, cold air from above displaces it, and the warm air is pushed upward. Air currents or winds are thus set up as portions of the air become warmer or colder. These currents overflow from one region to another, and the pressure of the atmosphere becomes unbalanced. This results in another flow of air from the regions of higher to the regions of lower pressure.

Land heats more quickly than water when the sun's rays fall upon it and also cools faster when the sun has set. As a result, land and sea breezes are produced near oceans and lakes. During the daytime the air warmed by the land becomes lighter, and winds are caused as cooler air moves in from the water to displace it. At night the air over the land cools more rapidly and moves out to displace the warmer air over the water. These sea breezes cool the land during the day and prevent the extremes of temperature often

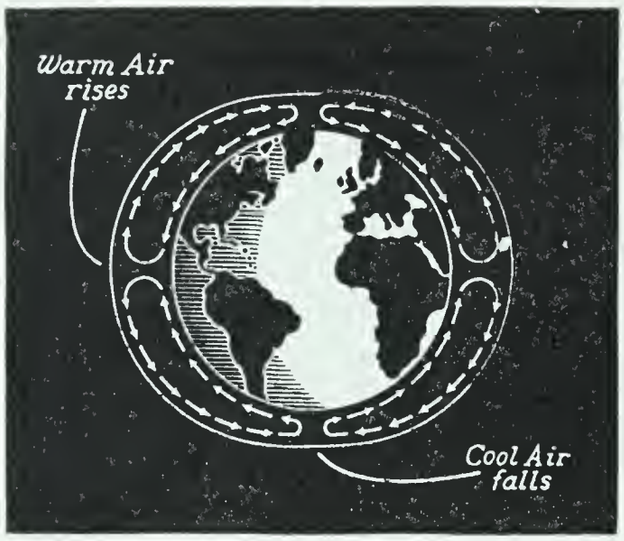


The direction of the breeze is reversed in the above drawing from that on the opposite page. Why? If given equal quantities of heat, which will warm the more, land or water?

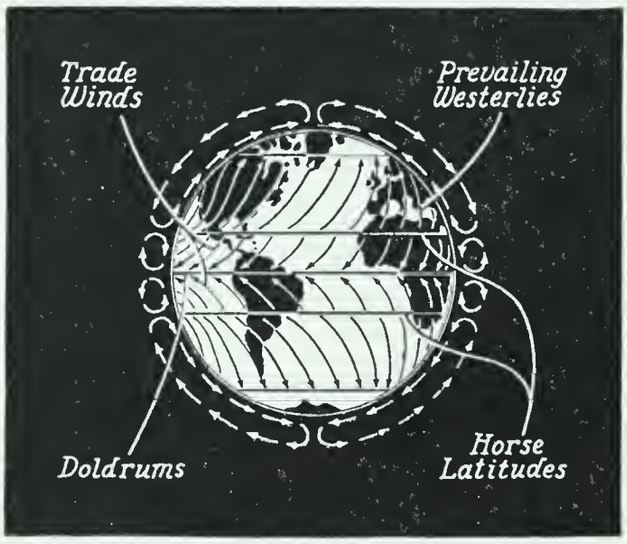
found in the interior. The sea breezes are strongest on the hottest days since they are caused by the difference in temperature between the land and water.

The gentle breeze known as the valley breeze which frequently blows up the sides of mountains on warm, clear days is also largely caused by a temperature difference. When the sun gets directly overhead, the mountain slopes are strongly heated, and the adjacent warmed air flows up the mountainsides, much in the same manner as an updraft in a chimney. After sufficient cooling has taken place at night, the breeze reverses and blows toward the valley. Experienced mountain campers, therefore, build their night fires below, not above, their tents to avoid the smoke.

Unequal heating of the air and the rotation of the earth combine to produce wind belts. As air becomes heated near the equator, it expands, rises, and overflows at higher levels toward the two poles. The cooling in polar regions causes a movement of the air at the bottom of the atmosphere from the polar regions toward the equator. Thus there is a tendency for a general circulation of air between the equator and the poles. As in sea-and-land



Air would circulate about the earth in this manner if the earth were stationary.



The rotation of the earth deflects the air currents.

and mountain-and-valley breezes, the immediate cause is a difference in temperature between two regions.

But for the rotation of the earth, the general circulation of air from the equator to the poles and back again would tend to follow the meridians in a north-south direction. However, the rotation of the earth turns the air currents moving from the equator to their right in the northern hemisphere and to their left in the southern hemisphere. Hence the equatorial winds blowing toward the poles quickly become southwesterlies in the northern hemisphere and northwesterlies in the southern hemisphere. Notice that winds are named according to the direction *from which* they blow. At the bottom of the atmosphere the winds moving toward the equator similarly become northeasterlies in the northern hemisphere and southeasterlies in the southern. These easterlies are remarkably constant and steady over the oceans, especially on the eastern sides, for about one-third the distance from the equator in both directions to the poles. They are called *trade winds.* It was the driving force of these northeast trade winds that Columbus welcomed on his voyage of discovery to America.

Near the equator the northeast and southeast trade winds meet in a zone which is dominated by currents of heated air rising vertically, rather than by these horizontal trade winds. This is the zone called the belt of *equatorial calms,* or "doldrums." Sailing vessels feared this region, for the vertical winds did not give them motive power and they frequently were becalmed for days.

At the poleward limits of the trade winds, that is, near 30° N. and 30° S. latitude, are narrow zones where vertical currents of air descending from the upper regions predominate, especially over the oceans. These belts are called the *horse latitudes.* The reason for this name is unknown. Much of this falling air joins the trade winds and travels back toward the equator. Many of the desert regions of the world, such as the Sahara and those in southwestern United States, lie in the horse latitudes. The dry air of the horse latitudes may have a parching effect upon the land, thus assisting in desert formation.

In the middle latitudes which lie above the horse latitudes, that is from about 30° to 60° latitude in either hemisphere, are the *prevailing westerlies.* In the United States and much of Canada, the prevailing winds blow from a westerly direction to the northeast. The relatively warm southerly and westerly currents often meet cold currents from the polar latitudes along an irregular and shifting boundary. Sometimes these cold polar currents dip as far south as the Gulf Coast of the United States or the shores of the Mediterranean in Europe. At the boundaries between them and the westerlies, storms, characteristic of regions lying near the tropics, have their beginnings.

Land-and-sea breezes, mountain-and-valley breezes, winds accompanying local storms, and other cross winds are eddy currents within the prevailing planetary winds; they are similar to the little swirls and eddies which are contrary to the main flow of a river. Hills, ravines, buildings, and other irregularities of the earth's surface also tend to disrupt the flow of the prevailing wind currents. Sometimes when winds seem to have no set direction, an observation of the motion of clouds across the sky will reveal the true direction of the planetary winds. Over the oceans, especially in the southern hemisphere, where there is less interference, the flow of the prevailing winds is stronger and steadier than over the continents.

• THE WATER CYCLE

Air always contains water in the form of invisible vapor mixed with the nitrogen, oxygen, and other gases. The sources of this water vapor are numerous, such as soil, lakes, streams, the evaporation of rain water, the transpiration of plants and trees, and the respiration of animals, but the biggest source is the oceans. Winds sweeping eastward across the great Pacific Ocean gather moisture, which they carry inland on the west coast and drop in the form of

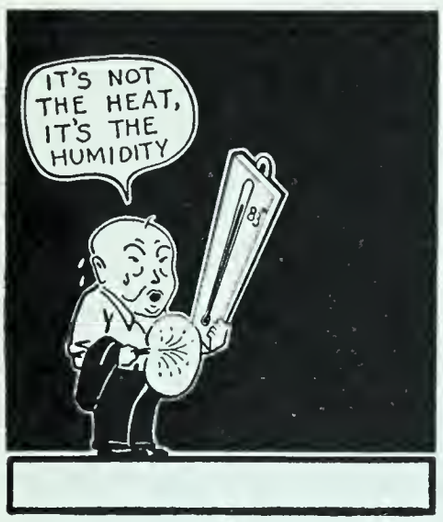
rain or snow as they cool in rising and crossing the high coastal mountain ranges. The Gulf of Mexico furnishes most of the moisture which winds carry to our Middle Western states, while the Atlantic Ocean serves this purpose along the east coast. This gathering of moisture by the air is the first stage of the water cycle. It also constitutes one of the most important factors in making the weather, for this vapor later forms fog and clouds or is precipitated as rain, snow, hail, or sleet.

The maximum amount of water vapor that can be present per unit volume of air depends upon the temperature. The water vapor is not absorbed or "held" by the air; it exists independently, just as it would if no other gas were present. There is a limit to the amount of water vapor that can exist per unit volume of air before the air becomes saturated, but the limit varies with the temperature. When we say that air is saturated, we mean that all of the water vapor that can possibly exist at that temperature is present, mixed with the air. In warm air, more vapor can be present than in cool air. Thus, nearly four times as much water is required to saturate a given volume of space at room temperature than is needed when the temperature is at the freezing point of water, 32° F. Air saturated at the freezing point becomes unsaturated if it is heated. There would, of course, be no change in the amount of water vapor present—merely an increase in the maximum possible value.

Air usually does not contain as much water vapor as could be present. The amount present at any instant depends upon the length of time it has been in contact with water and on its own temperature and that of the water at the time of contact. The temperature of the water is an important factor because the higher its temperature the more rapidly it evaporates into the air as vapor. The amount of vapor in a given volume of air is known as the *humidity* or *absolute humidity* of the air. If we find that the air in a room contains 10 grams of water vapor a cubic meter, we have determined the absolute humidity.

Relative humidity affects health and comfort. Evaporation of perspiration helps regulate the body temperature, which is held nearly constant while we are well. In order to change from liquid to vapor, water must absorb heat. Evaporation is a cooling process because the necessary heat is absorbed from the surroundings. The material which gives up this energy becomes cooler. Excess heat is thus removed from our bodies as perspiration evaporates.

When air is near the saturation point, the evaporating process



slows down; on the other hand, the change from liquid to vapor speeds up in drier air. In other words, the rate of evaporation depends upon the *relative humidity,* which is defined as the ratio of the amount of water vapor present in the air to the amount that could be there at that temperature. For example 17 grams of water vapor is the amount required to saturate a cubic meter at 20° C. If the air in a room at 20° centigrade actually contained 10 grams of water a cubic meter, the relative humidity would be $\frac{10 \text{ grams}}{17 \text{ grams}}$, or 58 per cent. A relative humidity of 58 per cent means that the air is 58 per cent saturated.

Relative humidity is a more useful item of knowledge than absolute humidity when we are considering the effects of various atmospheres upon health and comfort. Absolute humidity merely tells how much moisture is present in the form of vapor, but relative humidity enables us to judge whether or not evaporation from our bodies will take place at a desirable rate. Too rapid evaporation dries the delicate membranes of the respiratory system and chills the body. On the other hand, if evaporation is too slow, perspiration accumulates, and we become overheated. Our most depressing hot weather comes when high temperature and high relative humidity occur together. On such muggy days, the relative humidity may rise to 80 per cent or more. Even though there is no temperature change, we become more comfortable if the relative humidity drops. It is quite usual for it to drop to 30 per cent or even lower in some climates. Investigations indicate that we work most efficiently and maintain the best health records and that most people are comfortable when the indoor temperature is about 68° to 72° F. and the relative humidity about 45 per cent to 55 per cent.

Precipitation occurs when moisture-laden air is cooled. Clouds, dew, frost, rain, or snow forms when air is cooled so much that not all of its water content can continue to exist as invisible vapor. Each of these types of precipitation has its own peculiar conditions under which it forms. The cooling may occur as warm air is pushed into colder regions or as the air and the neighboring ground lose heat by radiation, as at night. The usual cause of the



Courtesy U. S. Weather Bureau

Telephone wires and trees are bending and breaking under their icy burden. Ice storms sometimes cause great damage.

upward motion of air is either heating at the surface or forced ascent up a topographical slope or over a mass of colder air along a "front."

Since atmospheric pressure decreases as the altitude increases, air from lower regions expands as it rises. Expansion of a gas is always a cooling process. It is this expansion during ascent which is the most important cause of the cooling which brings about condensation of moisture in the atmosphere; it is also the cause of the average decrease of temperature with elevation. Measurements show that the temperature of the atmosphere decreases at about the rate of 1° F. for each rise of three hundred feet. This continues until it finally reaches a temperature of about 70° below zero at distances above seven miles. Cooling of air by expansion during ascent causes it eventually to become saturated. Further cooling produces droplets of water which form clouds. If the particles grow large enough, they fall as rain. Snow forms when the temperature during the condensation is below the freezing point of water. When raindrops fall through cold layers of air near the surface of the earth and freeze, they form sleet.

Raindrops high in thunderstorm clouds may be thrown by strong upward currents to higher levels and freeze; falling again,

and again tossed up, a new layer of ice is added to the particles time after time. This process builds up hailstones the layer structure of which can be seen if they are split open. Finally, the hail becomes so heavy that it falls through opposing air currents and reaches the earth.

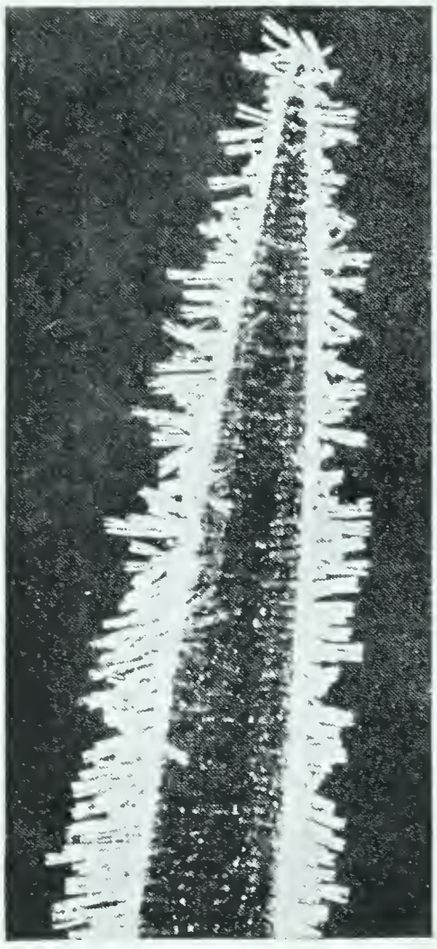
When the ground cools off during the night, it chills the air immediately above it. Eventually this cooling of moist air may cause it to lose some of its vapor by condensation. If the temperature at which this occurs is above the freezing point, water is deposited in the form of dew on objects at the surface of the earth. Frost forms when the temperature is below the freezing point. Should the air be sufficiently cooled for a distance above the ground, fog may develop; thus a fog is really a cloud formed near the ground. It may form either as quiet, moisture-laden air loses heat by radiation or as air blows to a cold region from another area where it has been warmed and laden with water vapor. The coasts of Maine and Newfoundland are noted for dense fogs which make their shores dangerous areas for ships at sea. The fogs form as air warmed by the Gulf Stream blows northward over the cold water of the arctic current. The California coast has areas where fogs form in much the same manner.

Dust in the air is both a menace and a necessity. Dust is necessary to the formation of fog, clouds, rain, and other types of pre-

The camera catches the tears of clover. Dew and excreted water furnish the point of interest.

Courtesy U. S. Weather Bureau





Courtesy U. S. Weather Bureau

The picture shows frost crystals on a blade of grass.

cipitation. Each raindrop contains a particle of dust around which the drop formed. The condensing process begins with ease only about something which serves as a nucleus. Although you cannot see them, there are thousands of dust particles in the space between your eyes and this book or in the amount of air which you take in with a single breath. In cities where factories pour huge quantities of smoke into the air, dust irritates the delicate linings of the nose, throat, and lungs and sometimes leads to infection of the respiratory system. However, without some dust in the air, the water cycle could not function effectively. Winds, aided by other natural processes, maintain at all times enough dust in the air to make these things possible.

Clouds represent another type of condensation. A definite type of cloud formation is typical of each stage of the weather cycle. Several kinds are often seen together in the sky, but one or more types are found to be rather regularly associated with each kind of weather.

There are ten types of clouds in the classification published by the International Meteorological Committee. The thin, white wisps of clouds that occur near the end of a period of fair weather are *cirrus* clouds. They are made up of tiny ice crystals formed at the top of the troposphere, usually at an altitude of about six miles. Cirrus clouds are the highest of all clouds. Their graceful, feather-like structure allows much light to pass through. They travel with the winds, sometimes at speeds exceeding 100 miles an hour, and help us to judge wind velocities at the level of the clouds.

The word *stratus,* meaning "layer," is used to describe a cloud which is much like fog in that it is uniform and blanketlike. Stratus clouds are the most common of all clouds and lie at lower levels, averaging less than one-half mile from the earth. They are gray in color and dense enough to conceal the sun and moon. Often rain follows periods when stratus clouds predominate.

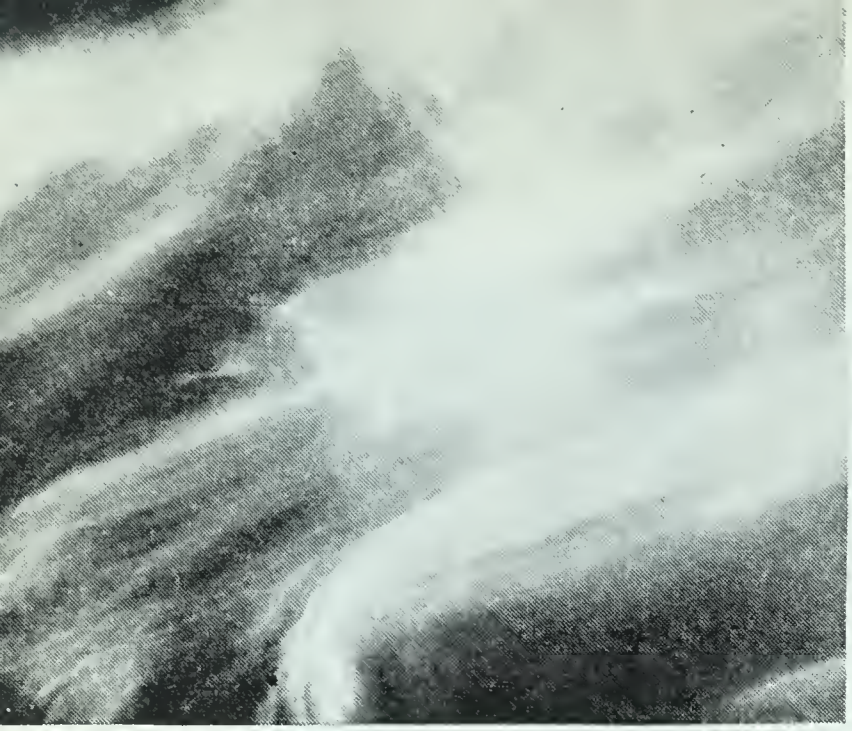
The *nimbostratus* cloud is the rain cloud. Since it usually, though not always, brings rain or snow, this heavy, dark cloud type is easy to identify. Likewise, the *cumulus* cloud is another type of cloud that is easily recalled. Cumulus clouds are the beautiful, brilliant-white, "wool pack" or cauliflower clouds which contrast so sharply with the blue sky. They are the fair-weather clouds frequently seen in the periods between storms. These comparatively low clouds are formed as warm, moist air rising from the ground during the day cools by expansion. They usually disappear at night leaving the sky clear.

The names of the other types of clouds have been formed in the same manner as nimbostratus, by combining a pair of the words, cirrus, stratus, cumulus, and nimbus, or by using one of them with "alto," meaning high. They are cirrocumulus, cirrostratus, altocumulus, altostratus, stratocumulus, and cumulonimbus. Photographs of some of these types are shown on pages 300 and 301.

• STORMS AND WEATHER FREAKS

Cyclones and anticyclones are the typical general rainstorms and snowstorms that sweep across North America. They may develop in Western Canada, the Pacific Ocean, or in western and southern portions of the United States—in general, all along the front where polar winds meet the prevailing westerlies. These disturbances travel as eddies within the westerlies and cause changes in the weather from day to day. Readings of barometers, which are instruments for measuring atmospheric pressure, reveal that the winds accompanying the storm sometimes circulate about a center of low pressure. These low-pressure areas range in diameter from one hundred to two thousand miles and are circular or oval in shape. Each depression follows its own path, but the general direction is from west to east; they usually depart by way of New England or the St. Lawrence Valley. These cyclones, as they are called, travel at an average rate of 20 to 30 miles an hour and pass across the United States in about three or four days. In the northern hemisphere, the winds of the cyclone spiral upward, inward, and counterclockwise; in the southern hemisphere they turn clockwise.

The counterparts of cyclones are the anticyclones. They are the high-pressure areas found between cyclones. Winds of the anticyclones blow spirally downward, outward, and clockwise in our hemisphere and counterclockwise in the southern hemisphere.



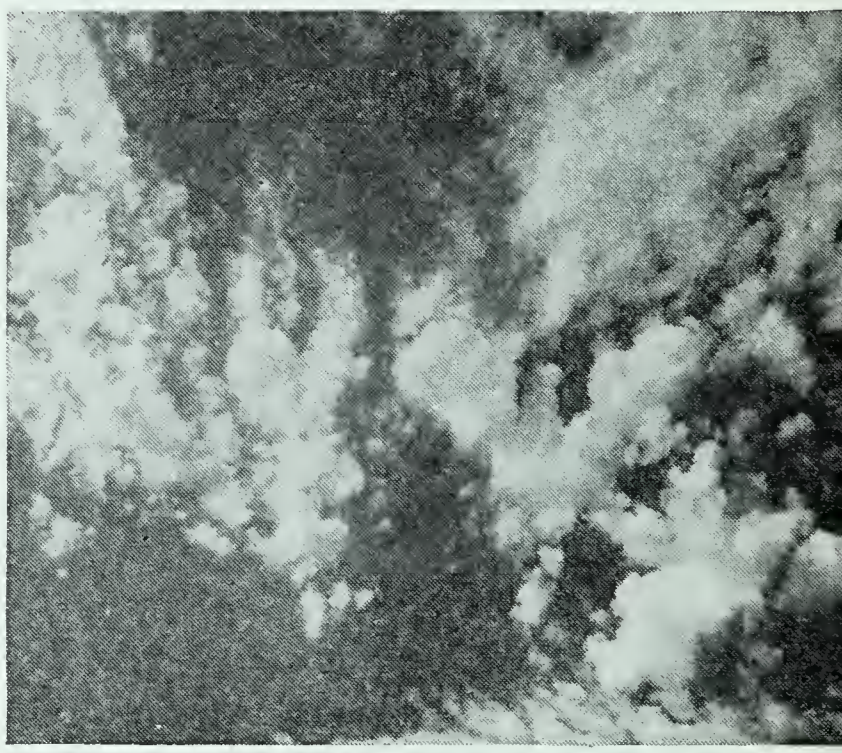
Mare's-tails, silky, white threads of cirrus cloud high in the air, warn that wind and rain are on the way.



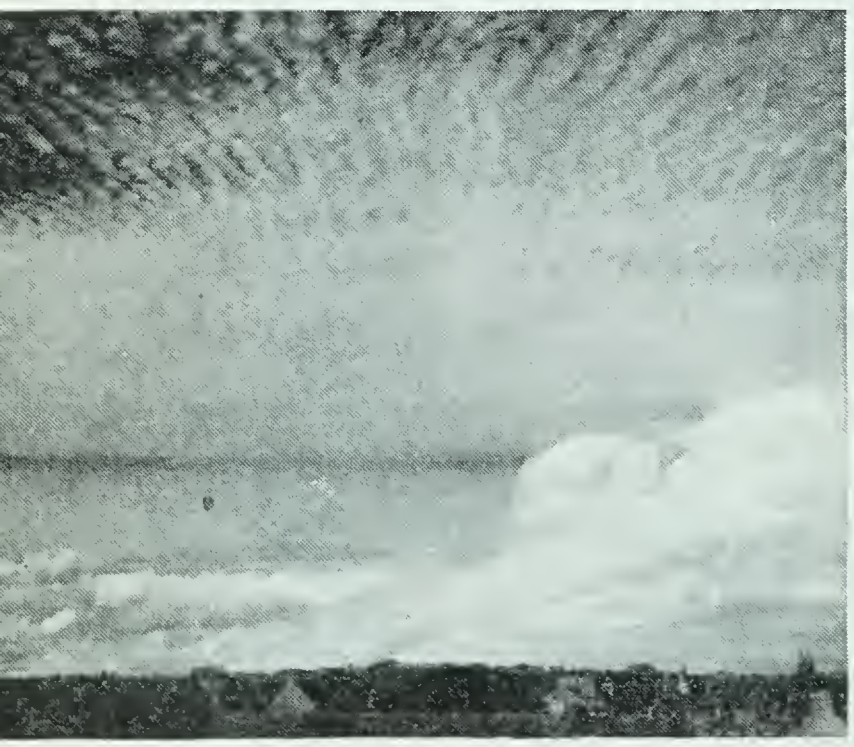
When cirrostratus clouds thicken until the sun disappears, the core of the storm is close, and there will soon be rain or snow.



When cumulus cloudtops spread into anvil shapes, a thunder shower may be expected in summer, a snow squall in winter.



Altocumulus or turret clouds, high and resembling shellburst, threaten thunderstorms within twenty-four hours.



Altocumulus clouds or "mackerel sky" has no certain significance though it sometimes means a weather change.



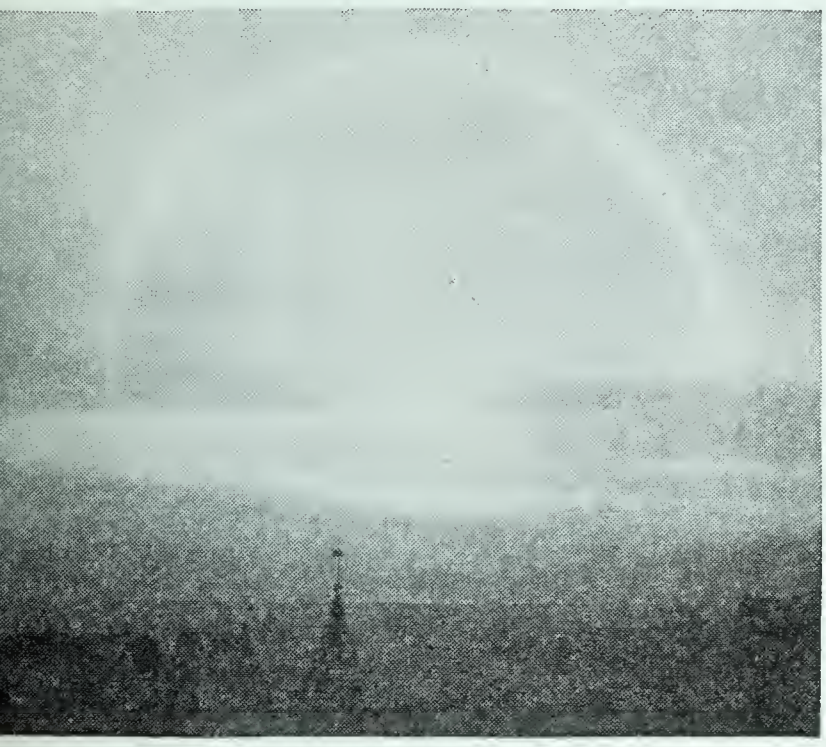
Small cumulus clouds of a summer day, if they do not gather size and grow vertically by noon, mean fair weather.



A cumulus cloud growing rapidly, its summit rising to a great height, indicates rain or hail and, in warm weather, lightning.



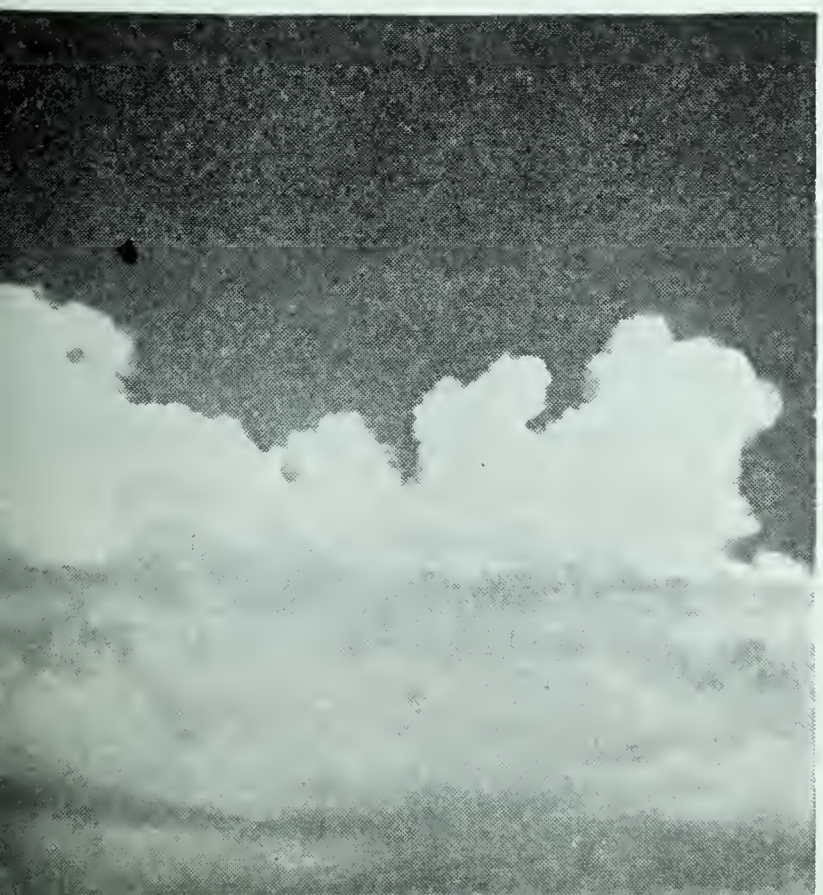
Bands or streaks of high clouds lying west to east and moving fairly rapidly precede a marked drop in temperature within a day.



Cirrus clouds, thin and pale and growing into a milky sheet across the sky, sometimes with halos, are a sign that the storm is nearing.



Stratocumulus clouds, hanging like curtains over the sky for days at a time, notably in winter, signify dry weather as a rule.



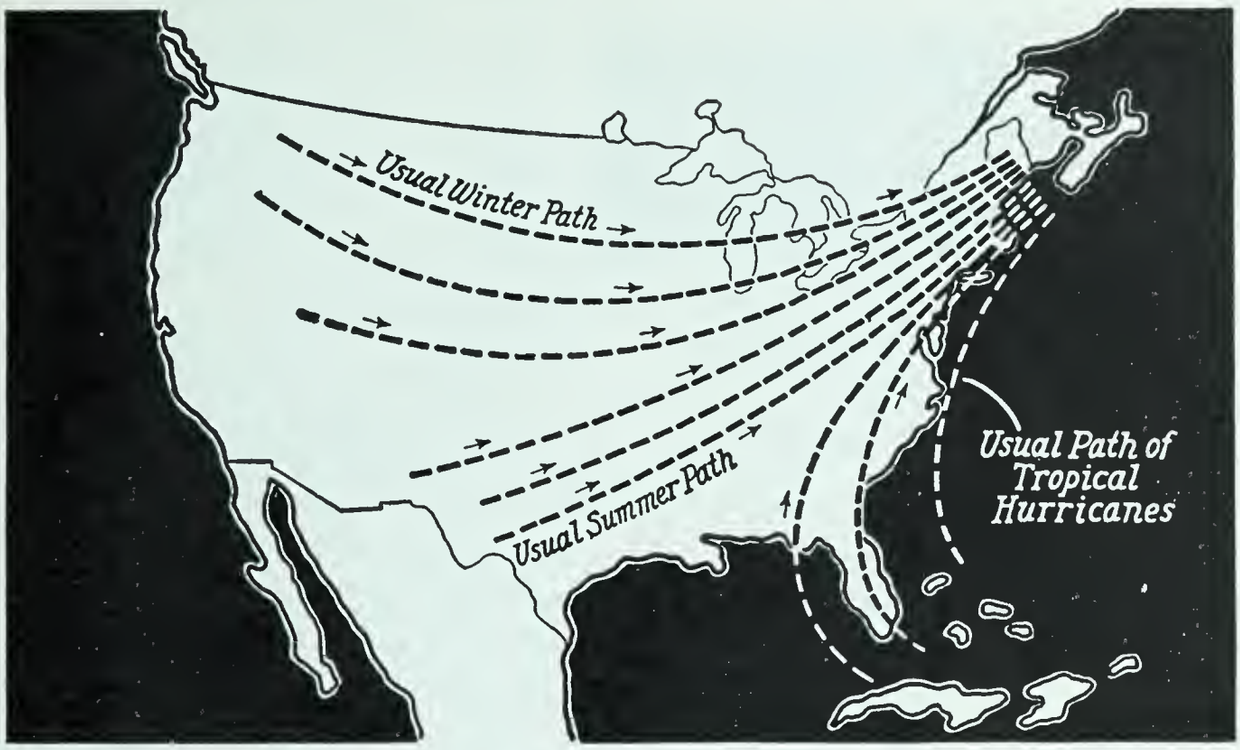
Clouds similar to "turret" clouds, but rising from a low cloud layer and forming "thunderheads," foretell the approach of squalls.

Photos courtesy George Aubourne Clarke, King's College, Aberdeen, Scotland



Science Service

No, this is not the North Pole! It is a weather observatory on top of windy Mt. Washington in New Hampshire. The frost grows thick and heavy in these parts. The highest wind velocities in the United States have been recorded here—more than 120 miles per hour.

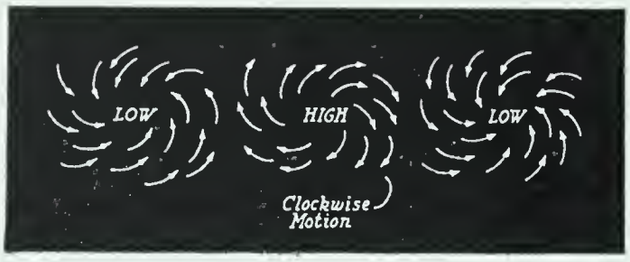


Cyclones and anticyclones usually follow these paths as they sweep across the United States.

Cyclones and anticyclones always alternate; they never occur in any other order.

Rotation of the earth produces the direction of circulation of the winds of "lows" and "highs." Air laden with moisture gathered from land and water areas expands and cools as it rises at the center of the cyclone. Herein lies the explanation for the clouds that always accompany lows and for the rain that commonly occurs with the passing of a cyclone. Anticyclones bring the clear, cool weather which follows the storm. As the winds become faint in a day or two, the temperature begins to rise, and sultry weather may announce the approach of the next "low."

Fortunately, tornadoes are rare occurrences in most places. These destructive, freakish twisters cover rather small areas but frequently do great damage. They develop locally as more limited, though more intense, cyclonic whirls in a low cumulonimbus cloud. They usually occur on spring days when the temperature difference between the cold air at higher levels and the warmer air rising from the earth is greater than usual. It is believed that velocities of 200 to 300 miles an hour are reached by the rotating winds near the center. There is also a tremendous updraft as the air at the center rises. The damage is done when the bottom of the *funnel* reaches to the earth.



These are the usual wind directions in cyclones and anticyclones.

In the United States, tornadoes are most common in the Middle West. They nearly always move from southwest to northeast and at a rate of about 20 to 40 miles an hour. The funnel-shaped cloud of the tornado can be seen approaching, and, if an automobile is available, one can usually get out of the storm's path by driving at right angles to its approach. If it is coming from the southwest, as tornadoes usually do, southeast or northwest would be the logical direction in which to flee. Strongly built underground cellars away from buildings provide a safe refuge from this type of storm. In the areas frequently visited by tornadoes, the authorities sometimes provide the schools with such near-by "cyclone cellars."

America's most costly disaster resulted from a tropical hurricane which got "off the beaten path." In 1938, this violent storm lashed the New Jersey coast, just missed New York City as it swept across Long Island, and then roared inland across the New England states, leaving a trail of destruction and death. The property



Ewing Galloway

This farmer's cyclone cellar also houses the acetylene plant which provides the farm with light and heat.



Ewing Galloway

Buildings burst outward as tornadoes pass. The air within them expands with explosive violence as the low-pressure center of the "twister" goes by.

damage alone exceeded the loss caused by both the Chicago fire of 1871 and the San Francisco earthquake in 1906. About seven hundred lives were lost.

Tropical cyclones, called hurricanes or typhoons, originate in the doldrums near the equator. Like tornadoes, they are violently whirling updrafts of air and are accompanied by heavy rainfall. Such storms which originate in the Caribbean Sea do some damage to the southern extremities of the United States almost every year. Less frequently they strike sections much farther northward. Generally they sweep north and eastward over the Atlantic Ocean where they "blow themselves out." August and September are the hurricane months. In 1900, one of these tropical cyclones killed thousands of people and destroyed millions of dollars worth of property at Galveston, Texas. Another particularly disastrous hurricane visited the Florida Keys in 1935.



Erpi Classroom Film

The distribution of electric charges in a "thunderhead" is indicated in the illustration.

Severe electrical storms usually occur following a period of excessive heat. Just how they form is not well understood, but the following explanation seems to be a plausible one. A local, but intense, cyclonic whirl produces a strong, chimneylike updraft. The water vapor in the rising and cooling air condenses rapidly, and the drops fall downward through the uprush of air which breaks them up and produces frictional charges. The fine mist and spray carried to the top of the cloud have a negative charge, while the larger drops which fall to lower levels have a positive charge.

When the electrical-pressure difference between the two parts of the cloud becomes great enough to overcome the resistance of the air, a huge electric spark occurs. This is lightning. If the two parts of the cloud drift apart, either one may induce an opposite charge on tall trees or buildings, church spires, and similar objects which it approaches; the lightning may then "strike" the object when the electrical-pressure difference becomes high enough.

The intense heat and molecular disruptions developed as the electricity forces its way through the atmosphere expand the air so suddenly that it has the explosive effect which we call thunder. The crackling sound heard near small electrical discharges is really thunder on a small scale. Cumulonimbus clouds are called "thunderhead" clouds because they bring the thunderstorms occurring during spring and summer throughout most of the United States.

The chances of one's being struck by lightning are very small, and they can be made still smaller by the observance of a few simple rules. Do not go outdoors during a thunderstorm unless it is necessary. If you must go out into the storm, do not go near hilltops or isolated trees and shelters; tall solitary objects are struck more often than are dense woods and low places such as deep valleys. Avoid wet materials; they offer less resistance than dry ones, and electricity takes the path of least resistance. Keep away from metal objects, since these are good conductors of electricity. Do not remain near fireplaces, since these are connected to the chimney and electricity is more likely to strike high points than

low ones. You are less likely to be struck if lying down than if standing erect. Artificial respiration should be applied if a person has been rendered unconscious by lightning. Shock by lightning is very often severe but not always fatal.

Skyscrapers and other tall buildings which have metallic framework offer better protection from lightning than do ordinary buildings. If the lightning strikes, the steel framework is able to carry the electricity to the ground without causing damage. This is the principle upon which the use of lightning rods is based. Should lightning strike, the rods conduct it to the earth if they have been properly installed and grounded. Insurance companies sometimes reduce rates of insurance on buildings protected by properly installed lightning rods.



Erpi Classroom Film

The upper, negatively charged portion of the storm cloud has drifted away, and the lower portion has come near farm buildings and objects on which it has induced an opposite charge. Where did the negative charges come from? What is the next step in the production of "lightning"?

Exercises for Problem Study and Review

1. What is weather? What is the weather like in the stratosphere? Where does weather occur?
2. Account for (1) the varying temperature throughout the day at a given locality; (2) the gradual drop in temperature toward the poles; (3) the general temperature levels of the four seasons.
3. By what method does insolation reach the earth? What happens to it when it strikes the earth?
4. Which is more important to weather—insolation received or insolation absorbed? Explain.
5. Why do we have seasons? Why does summer in the northern hemisphere occur when the earth is farthest from the sun?
6. What makes the wind blow?
7. Compare land and water as to their capacity to absorb heat. How do land and sea breezes result from these facts?
8. What combination of factors produces the prevailing wind belts of the earth? Why does the general circulation of the air from the equator turn to its right in the northern hemisphere and to its left in the southern hemisphere?

9. Account for the heavy rainfall on the western slopes of the mountains along the Pacific coast and for the scarcity of rainfall to the east of these mountains.

10. How does temperature affect (1) absolute humidity? (2) Relative humidity?

11. "It isn't the heat, it's the humidity." Explain the meaning and applications of this common expression.

12. The relative humidity is 80 per cent. Explain the meaning of this statement.

13. Explain the formation of (1) clouds; (2) fog; (3) rain; (4) dew.

14. Can water vapor exist in the air when the temperature is below 32° F.? How is this fact related to the formation of frost and snow?

15. Compare hail and sleet.

16. What causes clouds to form? Is it true that the types of clouds are "endless"?

17. From where do cyclones come? Where do they go? How fast do they travel?

18. Compare a cyclone and a tornado. How and where should you take refuge at the approach of a tornado?

19. How is lightning produced? How is thunder produced?

20. Name several places of comparative safety where you can take refuge during an electrical storm. What other precautions should you observe to "play safe" at such times?

21. What really happens when a person or an object is "struck" by lightning? What should be done when a person is rendered unconscious by lightning?

Problem 2: How has man improved his adjustment to weather?

• FORECASTING THE WEATHER

Today's weather report and tomorrow's forecast are one of the most popular radio features. In peacetime every station broadcasts news of the weather several times each day, and the audience probably numbers millions of eager listeners. But only the method is modern—the idea is very old. From earliest times, man has realized that he could regulate his life and activities much more satisfactorily if only he knew what kind of weather to expect a day or two before it arrived. Consequently, many schemes for predicting the weather have evolved.

"Rain from the east—twenty-four hours at least." "If red the sun begins his race, be sure that rain will fall apace." "Rainbow

at night, sailor's delight; rainbow in morning, sailor's warning." How many others can you add to this list of efforts to predict the weather in rhyme?

Who has not been advised to expect fair weather should he be fortunate enough to discover sufficient blue in the sky to make a Dutchman a pair of breeches and to interpret a ring around the moon as a sign of rain? The migration of wild birds, the thickness of the fur on animals, the emergence from hibernation of certain animals, notably our old friend the groundhog—all these are regarded as a means of predicting the weather by some superstitious persons. (As if these unsuspecting creatures were especially favored with advance information by Mother Nature, herself!)

Weather folklore is a confusing mixture of superstition and wishful thinking. Many common-sense prophecies involve generalizations based upon reliable observations, but generally the truth is hopelessly entangled in misinformation and sheer fiction. Thus it is wholly absurd to base weather predictions on the shape of the moon, as if that satellite were an unsteady container that now and then tipped over, bestowing some of its watery content upon the earth. On the other hand, the common saying that a ring around the moon is a sign of rain or snow bears some relation to fact. Such a ring is caused by the ice particles of high cirrus clouds breaking up the reflected light from the moon into colors and producing a halo similar to that seen around a street light on a foggy night. Add to this the fact that cirrus clouds are usually forerunners of rainy weather, and we have the facts which underlie the forementioned generalization. The scientist must carefully search out truth and fiction and seek generalizations that are supported by well-proved facts before true progress in weather forecasting results.

Modern weather forecasting has become a science. It is very complicated, because the factors which make the weather are themselves constantly undergoing change. It is true that, in general, lows and highs pass across the United States one after another and move the weather of one locality to points farther east. But, within the interplaying masses of air, the differences in moisture content, temperature, and pressure do not remain fixed. The passing of a low commonly brings rain, but it sometimes fails to do so. Consequently, before he can estimate the future weather, the forecaster needs to know the exact weather picture of a large part of the earth's surface; he must know the directions and velocities of the highs and lows and as much as possible of the



Courtesy U. S. Weather Bureau

Above is shown the launching of a sounding balloon or radiosonde at a weather station. This robot weather observer sends back radio signals which indicate the temperature, air pressure, and humidity at all heights reached. After the balloon bursts, the instrument comes to earth easily and lightly under the parachute, attached to the balloon.

changes that are taking place within them.

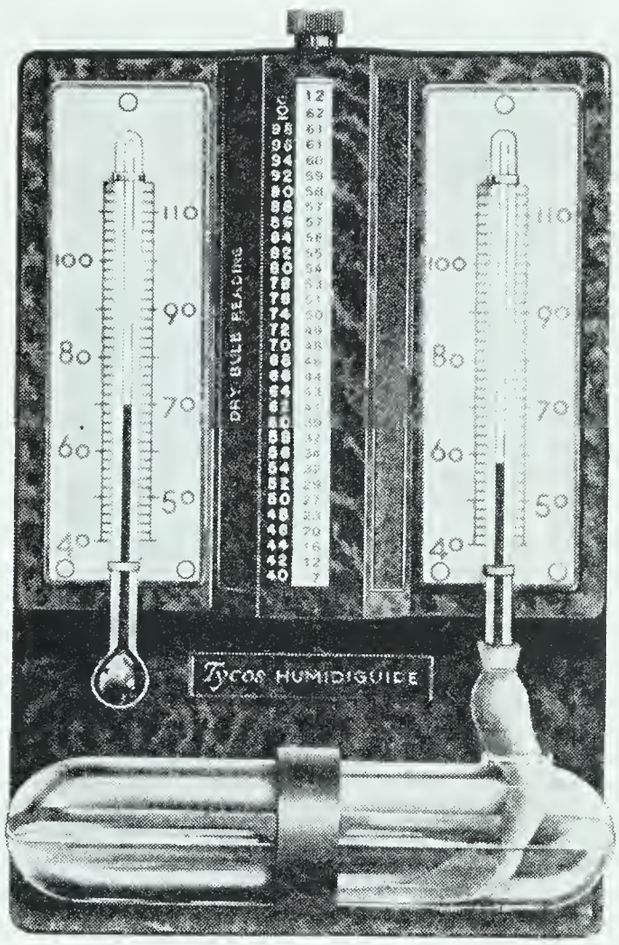
The United States Weather Bureau is the largest weather agency in the world. It gathers data four times each day from more than two hundred well-distributed stations in charge of full-time employees of the Weather Bureau. These stations make observations and recordings of weather conditions in their localities every six hours, at half-past seven and half-past one, seventy-fifth meridian time, day and night. There are also other sub-stations, of which some report regularly and others at special times. Ships at sea cooperate by sending radio messages of weather conditions over the oceans. The Weather Bureau also exchanges reports with Canada, Mexico, the West Indies, and the Philippines. Dur peacetime regular radio broadcasts tell of conditions in Europe.

Promptly at eight o'clock each morning and evening, when each station has completed its observations and recordings, the results are telegraphed to concentration centers, including the central office of the Weather Bureau at Washington. At certain stations, morning airplane flights or radiosonde balloon soundings are made to measure the conditions at higher levels. This information is also relayed to Washington. The weather maps are then prepared according to standard procedures and are telegraphed to centers throughout the country. They are published by many newspapers, and weather information is broadcast by radio stations.

The observation stations are grouped into sections, each having a concentration center at which smaller maps are made for portions of the United States. The centers receive weather data

telegraphed to them by a selected number of stations at the same time that all reports of observations are sent to Washington. For example, the New York office receives reports from more than 160 of the weather stations throughout the country. Chicago, New Orleans, Denver, and San Francisco are also forecast centers.

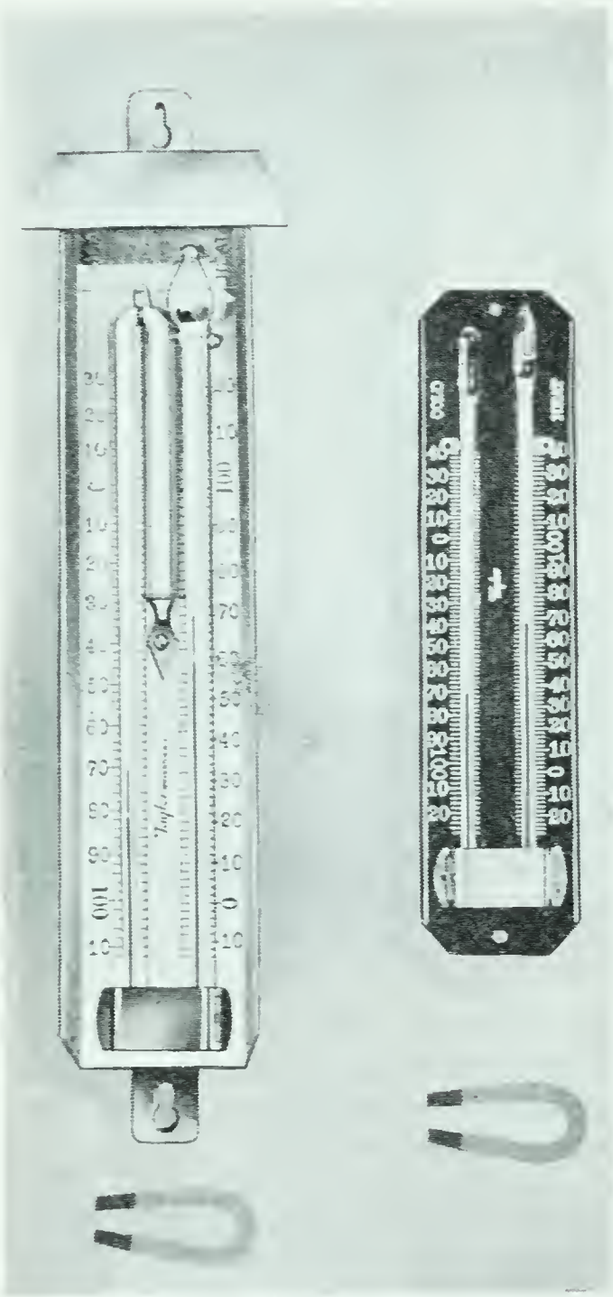
The observer's report tells the state of the air at a given time and place with respect to the "weather elements." The following analysis of these items received by the forecasters will aid us in understanding and reading the weather maps made to summarize the local station reports.



Courtesy Taylor Instrument Company

The difference between the reading of the dry-bulb thermometer and the wet-bulb thermometer gives the clue to the relative humidity.

Temperature and relative humidity. A "dry-bulb" thermometer reading is simply the temperature of the air obtained in the usual fashion by an accurate observation of a Fahrenheit thermometer, the type which we use in our homes. If the bulb of a similar thermometer is covered and kept moist by a piece of cloth which extends into a reservoir of water, the "wet-bulb" thermometer reading can be found; it will nearly always be lower than the dry-bulb reading. For the explanation of this difference, we return to a very helpful generalization which we have used before: namely, evaporation is a cooling process. The amount of difference between the two thermometers depends upon the rate at which evaporation takes place; the rate of evaporation, in turn, depends upon the relative humidity. Therefore, if the wet- and dry-bulb thermometer readings are known, the per cent of saturation can be obtained by finding their difference and referring to relative humidity tables which are based upon the differences that may occur at any temperature. The instrument which consists of a wet- and a dry-bulb thermometer is called a *hygrometer.*



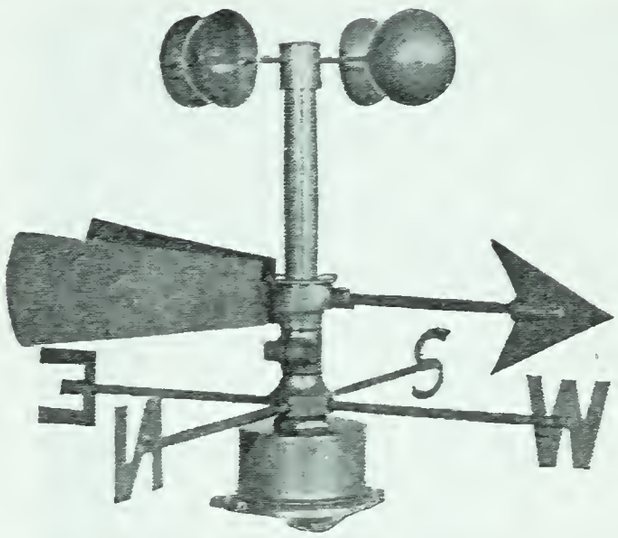
Courtesy Taylor Instrument Company

In this maximum-and-minimum thermometer, the magnets are used to set tiny metal indexes enclosed above either side of the thread of mercury. The indexes, surrounded by alcohol which can filter by without displacing them, move only when pushed by mercury. Note the direction of the "cold" and "heat" scales, and then try to figure out how the instrument works.

Maximum - and - minimum thermometers are used to obtain the highest and lowest temperatures that occurred during the twelve hours elapsing since previous readings. A common type of this instrument is similar to the ordinary thermometer except that the bore becomes smaller near the bulb. The mercury column breaks at this narrow part when it contracts upon cooling. In this way the top of the mercury column remains at the highest temperature reached. After each reading, the thermometer is reset by whirling. The liquid used in the minimum thermometer is alcohol. A small, movable glass index is within the stem of the thermometer, which is mounted horizontally. As the alcohol column contracts with a drop in temperature, the surface of the liquid carries the index toward the bulb. The liquid, when expanding with a rise in temperature, is not able to pull the dumbbell-shaped index in the opposite direction, and the index remains at the lowest temperature of the twelve-hour period.

Wind direction and velocity. The Weather Bureau stations determine the direction of the wind by means of a sensitive weather vane about thirty inches in length and mounted on roller bearings. They use the cup *anemometer,* similar to the one illustrated on page 313, to measure wind velocity.

Precipitation. Rain gauges are simply open vessels which catch the rain as it falls so its depth may be measured in inches. When snow falls, its average depth is measured, and its water equivalent in inches may then be obtained by melting the sample caught by the gauge. The observer reports the kind, amount, and direction of clouds after carefully examining them.



Courtesy Taylor Instrument Company

The revolving axis of this four-cup anemometer operates the gear system of a dial which indicates the wind velocity in miles per hour.

Air pressure. The pressure of the air is measured by means of an instrument called a *barometer.* The common types are the *mercury* barometer and the *aneroid* barometer. A mercury barometer can be made by sealing one end of a glass tube about 3 feet long, filling it completely with mercury, and inverting it with the open end within a vessel of mercury. The open end must be covered during the inverting process to prevent a loss of mercury and the entrance of air into the tube. Mercury flows out of the inverted tube, leaving a vacuum above, until the weight of the mercury within the tube is balanced by atmospheric pressure. The reading of such a barometer is obtained by carefully measuring the distance from the top level of the mercury in the vessel to the top of the mercury within the tube. The atmosphere at sea level can ordinarily support a column of mercury about thirty inches high.

Evangelista Torricelli, an Italian physicist, who in 1643 first made this kind of barometer, noticed that on some days the column of mercury rose a little above thirty inches and that on others it fell a little below. As we now know, the lows are associated with cyclones and the highs with anticyclones. During the approach of storms, the barometer reading ordinarily falls; during the clearing after the storms, it ordinarily rises. Barometer readings from all parts of the country thus enable the Weather Bureau to locate the low- and high-pressure areas at the time of the observations.

The aneroid barometer is less accurate but more convenient to carry about than the mercury barometer. It contains a corrugated metallic box in which the pressure has been reduced by

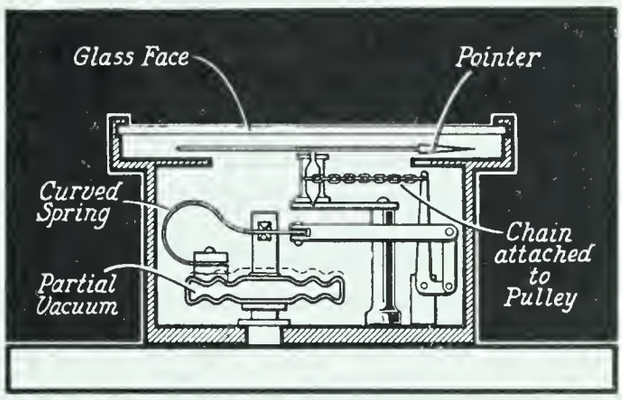


removing part of the air. The box undergoes changes in thickness as atmospheric pressure varies. A system of levers magnifies the motions of the top and moves a pointer over a circular scale. The scale readings indicate the pressure in millibars, inches, or centimeters, corresponding to the readings of a mercury barometer. The aneroid is the type of barometer carried by aviators. Since air pressure decreases quite regularly with gain in altitude, the scale may be modified so as to indicate the altitude instead of the air pressure. The instrument is then called an *altimeter*.

The "total correction" applied to the "observed reading" of the barometer in the station report of observations tends to eliminate variances in readings. These can be traced to

Courtesy *The Christian Science Monitor*

On January 1, 1940, when the Weather Bureau began to publish barometer readings in millibars, as well as in inches, there were only two "bar" barometers in the United States. Boston could boast of the one shown in the lower picture, while the Weather Bureau at Washington had the other. The upper photograph of an aneroid barometer shows the millibar readings which correspond to certain readings in inches. Which is the more logical barometer scale, the one which employs the metric unit for pressure, or the one which employs the English unit for length?



This drawing shows the construction details of the aneroid barometer.

the expansion and contraction effect of temperature changes upon the mercury, the differences in the attraction of gravity at different latitudes, and imperfections found in the individual barometer accepted as a standard. Since barometer readings are affected by differences in altitude, the corrected station reading is finally "reduced" to sea level by adding the appropriate amount if the station is above sea level or by subtracting if it is below. The amount added or subtracted depends upon the calculated weight that a column of air extending from the station to sea level would have if it existed.

Visibility. According to the Weather Bureau, visibility is the greatest distance in the direction of the horizon at which one can with the unaided eye see and identify prominent objects such as mountains or buildings. Fog, rain, snow, haze, dust, and smoke reduce visibility.

The Weather Bureau also keeps track of sunshine. Since plants depend upon the sun for foodmaking and growth, it is sometimes desirable for agriculturists to have records of the total amount of sunshine during certain periods when the growth of crops is being studied. The Weather Bureau gathers data on the available solar energy by means of its sunshine recorder. The operation of this instrument is based on another familiar principle, that dark, rough surfaces are better absorbers of heat than bright, shiny surfaces. It consists of two glass bulbs connected by a straight glass tube extending down into the lower bulb which is coated with lampblack. In the lower bulb are a little alcohol and some mercury. When both bulbs are in direct sunlight, the mercury is forced up into the tube by the expansive forces due to the absorption of radiant solar energy by the blackened bulb.

As the mercury rises, it makes an electrical circuit by completing a path for electricity between two wires sealed in the tube. An outer tube from which air has been removed surrounds the inner tube and bulbs and tends to prevent the transfer of heat from the atmosphere. The sunshine recorder measures the duration but not the intensity of the sun's rays.

When the current flows, it passes through a complicated device

which makes a mark on a register sheet for each minute of sunshine. The *meteorograph,* as this device is called, also keeps a continuous record of wind direction, wind velocity, and rainfall. It thus provides the observer with a check upon the individual readings which he relays to the forecast centers.

The weather map constitutes the basis of weather forecasting. When the data from the local stations reaches the forecast centers, it is immediately used to complete a weather map. From a study of the weather map, the meteorologist, as the weather expert is called, is able to make surprisingly accurate estimates of the weather that will occur during the next twenty-four to forty-eight hours in the various sections of the country. He is aided by past experience with the behavior of the weather in the different areas. He knows what weather has resulted previously when former maps showed conditions similar to those revealed by the current one. His predictions do not always come true, but past records reveal that 85 per cent to 90 per cent of the Weather Bureau forecasts published and broadcast throughout the United States are accurate. As these percentages indicate, the understanding of the atmosphere is not complete, and other means have been sought to supplement the analysis of the "highs" and "lows."

The Weather Bureau now issues long-range weather forecasts one week in advance. This new method of forecasting based on observations that include data from arctic and subarctic areas was put into effect in 1940. Very specific information about the structure of the air itself is required so that it can be divided into warm- and cold-air masses and fronts. Cold-air masses in the United States descend from Canada and the northern Atlantic and the northern Pacific Oceans. Forecasting by this method depends upon the ability to predict what will happen when these masses of cold air meet warm masses from the south. Information about the structure of the air at levels near the stratosphere is also needed. It is obtained by airplane flights and also by releasing radiosondes—balloons about 6 feet in diameter which carry aloft automatic weather-recording instruments connected to a miniature radio transmitter that sends the reports on atmospheric conditions to ground observers. Parachutes are attached to the various instruments to float them safely to earth when the balloon bursts at high altitudes. What do you think causes the balloons to burst?

Information about the upper levels of the atmosphere and the arctic and subarctic air masses is plotted on a hemispherical rather than a continental map. Forecasts are really interpretations of

what seems to be happening in the "weather drift" around the northern part of the hemisphere. Observations indicate that in this "drift" there are areas of high and low pressure moving around more or less rhythmically. When these "weather waves" are definite enough, predictions can be made with a fair degree of accuracy; when they are poorly defined, the forecasts are questionable. Experimental forecasts for one week in advance have shown an accuracy of 70 to 75 per cent.

The forecasts are not specific but simply outline an expected trend of the weather. They are issued twice weekly, and the first day of each period overlaps with the last day of the preceding period. The week-end forecast, issued Fridays, covers Saturday, Sunday, Monday, Tuesday, and Wednesday, while the Tuesday forecast covers Wednesday, Thursday, Friday, and Saturday.

The advantages of such long-range forecasts over predictions for only thirty-six hours in advance are numerous; their value to agriculture, aviation, and other industries may amount to millions of dollars a year. Farmers can plan their planting and harvesting to take advantage of future weather. California and Southern fruit and vegetable shippers can know with a fair degree of accuracy what kind of weather to expect on shipments to the North and can prepare against sudden drops in temperature. With advance knowledge of heavy rains, residents of river valleys could prepare for floods days in advance. City vacationists could plan their country, mountain, or seashore outings with a greater degree of certainty of favorable weather. Managers of outdoor athletic events should find the long-range type of forecast very valuable.

The Weather Bureau has warned, however, that the public should not expect more of long-range forecasting than is reasonable. In the words of one weather man, "We can tell you what to expect in general, but that doesn't mean we can assure you that next Saturday will be a fine day for swimming."

The Weather Bureau renders other services in addition to the semiweekly and daily forecasts of the weather outlook. Special forecasts or warnings are issued when weather is expected which may threaten life and property. It maintains special facilities at Washington, Jacksonville, New Orleans, and San Juan, Puerto Rico, for gathering information about the approach of hurricanes and for sending warnings to the land areas which may be affected and to vessels at sea.

It performs special services for the farmer. Fruit-frost stations located in Florida, Texas, California, Oregon, and Washington



Courtesy U. S. Weather Bureau

Five-quart lard-pail heaters being used to prevent the formation of frost on fruit trees.

give warnings of frosts which may damage fruit crops. The central office at Washington issues a weekly Weather and Crop Bulletin which informs of the general condition of crops throughout the country. There are also special bulletins for the principal crop areas such as the wheat and cotton regions.

The Weather Bureau provides river and flood service which is of great value to towns and cities as well as to rural areas. Because of their interest in the condition of the rivers, the United States Army Engineer Corps and the United States Geological Survey aid in the installation and maintenance of river gauges. The Bureau keeps track of the water level at points along the important rivers whose overflow might cause considerable damage, and it makes forecasts of crests likely to be reached by rising flood waters. These warnings often prevent loss of life and property.

Frost prevention is economically practical only where the frosts are light and rather infrequent. Such control is extensively practiced in the great fruit-growing sections of California and to some extent elsewhere, especially in Florida. A knowledge of how frost occurs suggests the way in which it can be prevented—it is necessary only to keep the air from being cooled to the saturation temperature. The heating of the atmosphere about orchards when frost threatens to form is done by burning oil in containers scattered among the trees. Since clouds of smoke roll from the open vessels as the oil burns, they are called "smudge pots." Contrary to former opinion, it has now been proved that the smoke itself does little except create a nuisance as the soot settles on dwellings. Therefore, more efficient smokeless burners are gradually replacing the older and more wasteful ones.

Many farmers have automatic gongs which sound during the night when the temperature on the attached thermometer drops within a few degrees of the freezing point. If the gong sounds just before sunrise, the fruitgrower need not do anything, since he knows that the sun will soon drive the temperature higher.

When the warning comes earlier in the night, he must hurry to light the burners.

• WEATHER MADE TO ORDER

Today the term "air conditioning" calls to mind the newer practices of indoor weather-making which Willis H. Carrier and Stewart W. Cramer independently developed and applied to cotton mills about 1906. Although the use of air-conditioning systems spread rapidly to many industries, its use in other fields lagged. The first motion-picture theater was not fully air conditioned until 1922. When this venture proved profitable because of increased patronage during summer months, owners of department stores, hotels, restaurants, etc. also adopted air conditioning. Small installations of the kind used for railway coaches, homes, and other small buildings made their appearance about 1930.

Complete air conditioning consists of regulating the temperature and humidity of the air and in assuring its proper circulation and cleaning. Although man has been doing something about indoor weather ever since he first learned the use and control of fire, he was not conditioning the air in the modern sense until the beginning of the twentieth century. Fire permits an increase in air temperature through the addition of heat but does nothing towards controlling the amount of moisture in the air or toward cleaning it. Properly conditioned air serves two important functions in the life of man: (1) the air must supply oxygen at all times; (2) it must have the capacity to carry away waste body heat, not carrying it away so fast that we become chilled, and not too slowly lest we become overheated.

It is almost impossible to find air which does not have sufficient oxygen to support life. A simple test is similar to that used in some mines. In these mines, candles are burned to indicate whether the oxygen content is sufficient for the miner. If the candle goes out, the miner knows that he is in air with a low oxygen content. The candle goes out when the oxygen content is 16 per cent. The miner is not in grave danger until the oxygen content is 14 per cent or lower. In order to know if the air has "enough oxygen for breathing," try striking a match. If the match burns, there is sufficient oxygen for life.

A function of air, to remove body heat, has long been realized. If the air is too cold or if the moisture content is unsuitable, the waste heat of the body is removed so fast that a person becomes

chilled. If the temperature is too high and the moisture content excessive, the body becomes overheated, as it does not lose its waste heat as fast as it is generated. In both cases, the circulation of air is important to prevent the human body from becoming enveloped in a layer of air which approaches body temperature. Conditioned air for personal comfort means the control of temperature, humidity, and circulation to assure the correct rate of removal of body heat to maintain comfort.

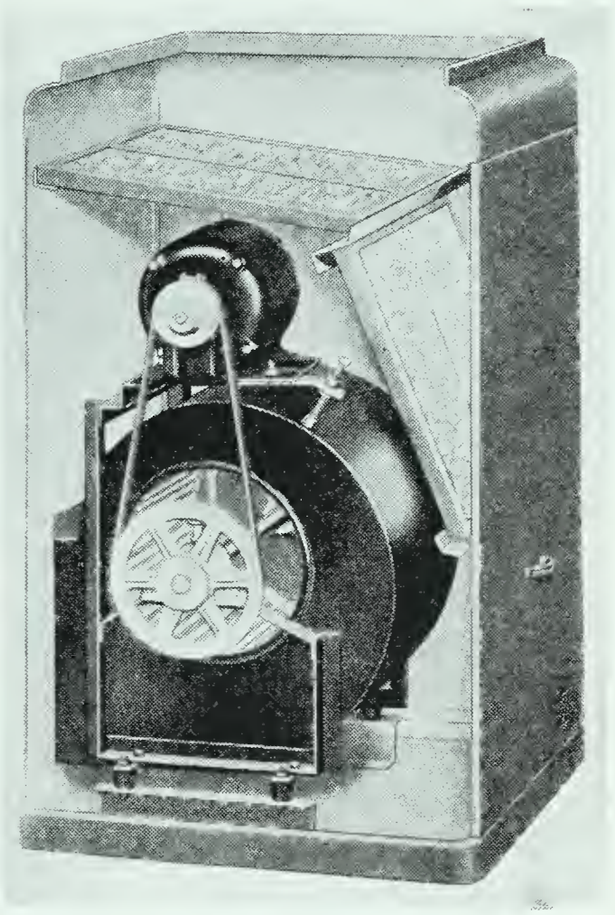
Circulation of the air must be carefully regulated to insure maximum comfort. A fan or blower capable of moving a large volume of air at a slow rate is the type needed. Proper circulation maintains uniform temperatures throughout the room, eliminating the uncomfortable and unhealthful condition in which the air near the floor of a room is much cooler than that at higher levels. The circulation must be slow so as not to produce undesirable drafts.

Whether air is healthful and comfortable in regard to moisture content really depends upon its degree of saturation. In other words, the important consideration is: what fractional part of the greatest amount that *could* be present *is* present. This fraction expressed in per cent is called the *relative humidity*. When the relative humidity is too low, evaporation of perspiration from our bodies takes place too rapidly, and we lose heat too rapidly. If the relative humidity is too high, the rate at which perspiration evaporates slows up, and we experience difficulty in getting rid of excess heat and become uncomfortable.

The water-vapor content of air is highly variable when heated in our buildings during cold weather. Air is often so dry that it is believed to be detrimental to health. On the other hand, you can probably recall hot, "muggy" days in summer, when excessive water vapor in the air added greatly to your discomfort. Obviously, moisture control is one of the important services rendered by air conditioning.

Bringing in outdoor air cannot be depended upon to bring in the right amount of moisture to produce the desired relative humidity—45 to 55 per cent. Indeed the moisture in the outdoor air provides these limits indoors only part of the time. Moreover, the relative humidity decreases rapidly as cool or cold air enters a building where it is heated. This, of course, is due to the increase in the maximum amount of water vapor possible for the given space, without any increase in the amount of moisture actually present. Consequently, indoor air in the wintertime

usually has a very low relative humidity, frequently as low as 15 per cent to 20 per cent. It is often worse than need be, because during the winter we commonly overheat the buildings in which we live. The drying effect of such air upon the delicate linings of the nose, throat, and lungs is no doubt partly responsible for the prevalence of colds, sore throat, and pneumonia in the United States during the winter. In addition to its harmful effect upon health, dry air has other disadvantages—such as causing the drying out and cracking of furniture and woodwork.



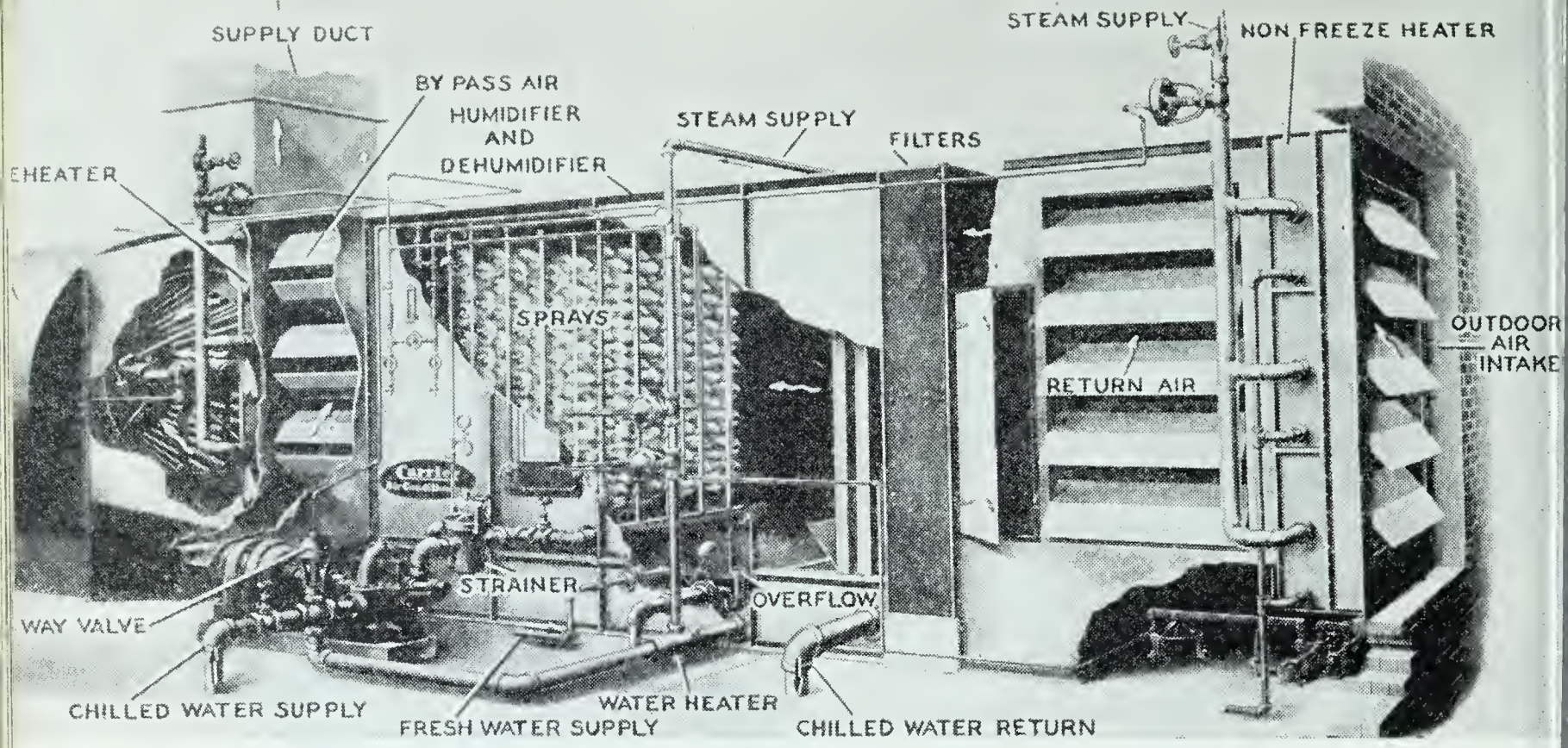
Courtesy American Radiator and Standard Sanitary Corporation

The dust filter above is designed to be built into the heating system as an integral part. Do you think it will become standard equipment for the home?

Air-conditioning installations add moisture to air in a variety of ways. In some systems the air is passed over pans which expose a large area of water to the air. Heat is provided by hot coils in the water or by other means in order to promote evaporation. In other systems the air stream passes through sprays of water formed by squirting water from a jet against a target or by spraying it from a special nozzle. The temperature of the spray water is controlled to obtain the desired relative humidity in the treated air.

Where mechanical air-conditioning systems are not provided, some improvement in humidity is obtained by placing pans of water in hot-air systems and by attaching vessels of water to the radiators of other central-heating systems. However, the amount of water vapor that passes into the atmosphere from such devices is usually small in comparison with the amount needed. In fact, when the outdoor temperature is 32°F., it would be necessary to evaporate about one pint of water an hour for proper moisture conditioning of the atmosphere in an average-size living-room.

When the moisture content of air is too great, modern air conditioning provides for moisture removal. It is desirable to remove



Courtesy Carrier Corporation

Study this drawing of an air-conditioning unit, and explain where and how it accomplishes the various steps that constitute air conditioning.

heat as well as moisture from air during hot, humid weather. It is possible to do both at the same time, because cooling an area reduces its moisture-holding capacity. Sufficient cooling causes moisture to condense out of the air. The cooling is done by passing the air through a cold spray of water or over a cold surface. The cold surface is frequently provided in the form of coils through which cold water flows or by means of coils cooled in the same manner as are the cooling coils of a refrigerator. Whether the spray or the cold-surface method of cooling is used, the temperature must be very carefully regulated in order to insure the desired relative humidity in the conditioned air.

Another feature of complete air conditioning is air cleaning. This means ridding the air of dust, pollen, and other harmful materials. It is usually accomplished by filtering or washing. A common type of filter is made of spun glass which is coated with oil or some sticky material to catch and hold the dust as the air passes through the filter. Such a filter must be washed and recoated from time to time or be replaced by a new one.

Air washing consists of passing the air through fine sprays of water and then against baffle plates upon which the dust collects. Where spray nozzles are used in the moisture control for adding or removing water vapor, they also provide for air cleaning. Washers have an advantage over filters in that they do not become clogged, thereby reducing the efficiency of the system. Because washing does not effectively remove oily dusts, a combination of both air washers and air filters is often used.

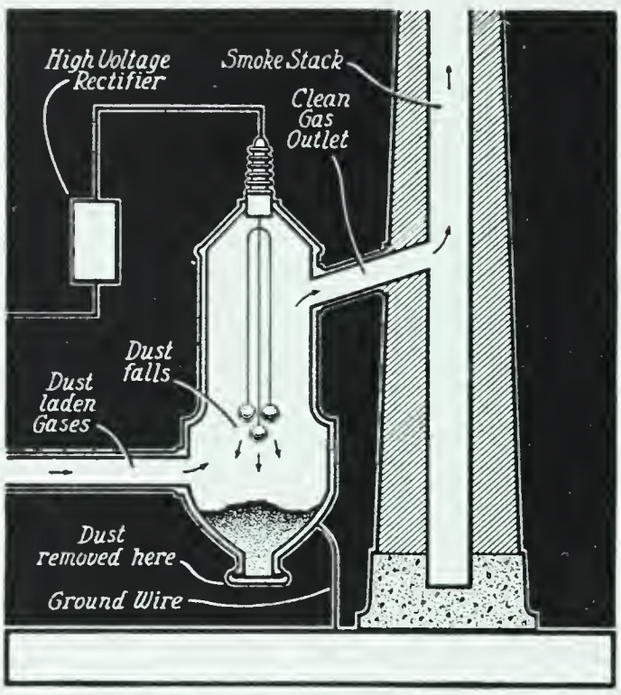
Electric "dust magnets" have also been invented to rid the air of pollen, smoke, and dirt. House dusts which have long been the bugaboo of many sufferers from asthma, hay fever, and other diseases caused by air-borne particles can now be almost completely controlled. Dust-free air, purged of the microscopic dirt and bacteria floating in it, can now be had by homes, factories, hospitals, and offices. The machine which makes this possible is an electrostatic air cleaner; it removes dust particles which mechanical filters allow to pass through.

As the air begins the electric cleaning process, it passes between tiny, hairlike wires charged with perhaps 12,000 volts of electricity. Here the dust particles pick up negative charges. Then the air passes through a collector cell made up of a series of highly charged plates. The negative dust particles are attracted to the positive plates and adhere firmly. The cleansed air passes on through the machine and is circulated throughout the room or building. The cost of operating the electrical filter is low—for the average home, about as much current being required as for a 60-watt lamp. At intervals of a month or six weeks, depending on how much dirt there is in the air, the plates of the collector cell are removed and cleaned. In one test of these machines, one-sixteenth of an inch of dust collected on the plates of the collector cell in one week—dust which otherwise might not even be noticed. A particle of cigarette smoke is about four-millionths of an inch in diameter. Billions of particles are blown into the air with every puff. But even they are not too small or too numerous for the electric "dust magnet" to handle.

In the practically dustless home made possible by this machine, the frequency of washing curtains and draperies and cleaning wall paper will be greatly reduced. Upholstered furniture will stay clean longer.

Machines which "wash" air by electricity have been used industrially for years. Many valuable materials were being lost in the form of smokes passing from the stacks of smelters, cement mills, paper mills, and factories. Furthermore, it was known that the carbon particles of ordinary smoke are destructive to our clothing and our homes and are detrimental to our health. Dr. F. G. Cottrell devised an electrical method of reducing ordinary smoke and recovering valuable materials from certain others.

The smoke-laden air goes past an electrode supported near the center of the chimney; surrounding it is a plate electrode. Both are connected to a high-voltage source of D.C. electricity. As the smoke



The Cottrell precipitator makes possible more healthful air by preventing dust from reaching the atmosphere.

particles pass the central electrode, they receive an electric charge of the same kind and are then attracted to the plate electrode of opposite charge. Here they are discharged and the precipitated dust is collected. This machine is known as the Cottrell precipitator.

Air conditioning provides many benefits, but does not necessarily reduce the over-all cost of heating a building. It is true that when a building is properly humidified in winter, body comfort is obtained at lower temperatures than otherwise. The cost of operating the humidifier, however, probably very nearly equals the amount saved by the smaller quantity of fuel needed to maintain the lower temperature. Furthermore, it costs money to get rid of excess heat and moisture during summer months. Buildings which are properly constructed for air-conditioning units make possible additional savings in fuel, since they are nearly airtight when the doors and windows are shut and are well insulated. Thus, when well built, they keep out the heat of summer and hold in the heat in winter.

As a general rule, managers of restaurants, stores, theaters, and offices are satisfied that air conditioning pays real dividends. This is especially true during summer months. People give preference to air-conditioned stores and theaters, they eat more food in an air-conditioned restaurant, and the efficiency of workers in air-conditioned surroundings is higher than when hot, "muggy" conditions prevail. Some churches have noticed a marked increase in summer attendance after air conditioning was installed.

Exercises for Problem Study and Review

1. How do you account for the large amount of folklore about weather? Is any of it of any value?
2. Why do weather forecasts frequently fail to materialize?
3. How are data collected for use in making weather maps?

4. List the weather factors observed and reported by the observer and make a statement as to the importance of each one.

5. Tell which of these factors would affect the height of the mercury column in a barometer and give reasons for your answer: (1) diameter of tube; (2) length of tube; (3) slant of tube; (4) moisture in the air; (5) altitude.

6. Tell what is being done to make long-range weather forecasting accurate. Why?

7. Describe the other services rendered by the Weather Bureau.

8. How do fruitgrowers attempt to overcome weather conditions that threaten their crops with frost? What science principles do they use?

9. What does complete air conditioning include?

10. How can moisture be added to or removed from air blown through a spray of water?

11. Why is relative humidity such an important item in conditioning the air of our homes?

12. How can dust be electrically removed from air? What law of electricity is applied?

13. Would you save money by having your home completely air conditioned? Explain.

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. State the composition of the air. Which component of the air is most important in relation to weather changes?

2. What hours of the day are generally the coldest? The warmest? Does air take longer to warm up or to cool off? Why?

3. In late fall and in winter, why is it colder on a clear night than on a cloudy night?

4. As we ascend higher into the atmosphere, the insolation becomes more intense, yet the temperature continually drops. How do you explain this?

5. As the day advances, what would you expect to happen to the relative humidity? The absolute humidity? Explain.

6. What would be your conclusion if the readings of a dry-bulb and a wet-bulb thermometer were nearly the same? Why?

7. From the diagram on page 304, figure out the direction of the wind and how it shifts at a given locality as a low approaches and passes (1) directly over the locality; (2) to the north; (3) to the south. Do the same for a high.

8. Is a building more likely to be crushed or to blow apart during a tornado? Why?

9. Why do frost and dew usually form on clear, cloudless nights?

10. "Weather and climate are natural resources." Do you agree with this statement? Why?

11. Why is the climate more unchanging along the coast than inland?

12. How does an electric fan cool us on warm days?

13. Why does the air have a nearly constant composition?

14. Chemical compounds have a constant composition. Is air a compound? Give some proofs for your answer.

15. What kind of day is best for drying clothes? Why?

16. What is the most likely cause of discomfort when several people are confined to a small, closed room for a period of time?

17. How does weather forecasting illustrate "the scientific method in action"?

18. How does weather illustrate cause-and-effect relationships?

UNIT WORD LIST

atmosphere
stratosphere
troposphere
insolation
radiation
convection
conduction
trade winds
doldrums
prevailing westerlies
horse latitudes
humidity
relative humidity
cyclone
anticyclone
barometer
tornado
lightning
thunder
hurricane
radiosonde
hygrometer
aneroid barometer
altimeter
Cottrell precipitator
high
low

INTERESTING THINGS TO DO

1. Keep a record of the weather man's predictions for a period of time, such as a month, and compare with the weather as it occurs. Calculate his "batting average."

2. Calculate the per cent of accuracy of a weather almanac for a period of time.

3. Visit a weather-bureau observing station and report on it to the class.

4. Make a list of common rhymes used in predicting the weather and evaluate the usefulness of each one.

5. Study each day's weather map for a period of days, and follow the progress of highs and lows across the country. Study other chang-

ing conditions, such as the freezing line, rain, and snow. Summarize your studies in a report, "How Weather Marches Across the United States."

6. Try your hand at predicting the next day's weather from a study of local conditions and conditions reported on weather maps. Do this for a period of at least a week.

7. Newly built houses are frequently advertised as "air conditioned." Investigate three or four such houses and report to the class your evaluations of the air conditioning provided in them.

8. Make a rainfall map of the United States.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Man's explorations of the stratosphere.
2. Climates of the United States.
3. Weather forecasts in relation to aviation.
4. Importance of weather knowledge in modern warfare.
5. Long-range weather forecasting methods.
6. Methods of air conditioning homes, theaters, department stores, and other buildings.
7. The work of the United States Weather Bureau.

INTERESTING BOOKS TO READ

Brooks, Charles F., *Why the Weather.* Harcourt, Brace and Company, New York, 1935. A popular story book of the weather containing an interesting collection of notes and anecdotes about weather.

Humphreys, W. J., *Rain Making and Other Weather Vagaries.* Williams and Wilkins Company, Baltimore, 1926. The author explodes many common myths and superstitions about the weather.

Humphreys, W. J., *Weather Rambles.* Williams and Wilkins Company, Baltimore, 1937. The reader will enjoy roaming mentally with the author as he relates interesting tales about the weather.

Pickwell, Gayle, *Weather.* Hugh F. Newman and Company, Los Angeles, 1937. Outstanding for its beautiful, full-page illustrations of weather phenomena.

TELLS OF ADVANCE IN RECLAMATION

Commissioner Page Reports Creation or Protection of $4,500,000,000 Values

SERVING SIXTEEN STATES

Can Make Low-Cost Power for the Defense Industries as Needed, He Says

SOIL CONSERVATION SHARPLY EXPANDED

435 Local Districts Embrace 271,000,000 Acres

Special to THE NEW YORK TIMES.

WASHINGTON, Jan. 1—With about 1,600,000 farm families living in 435 local soil conservation districts, covering 271,000,000 acres in thirty-seven States, the United States starts the new year better equipped than ever before to solve one of its major agricultural prob-

Waves, Tide Wash Into Shore Towns

Special to Newark News.

SEA BRIGHT—An unusually high tide and a heavy sea last night and this morning in the ocean and Shrewsbury River sent huge breakers over sea walls and flooded lowlands for more than a mile in this borough and at Monmouth Beach.

A number of automobiles, trapped in sand and water, were marooned. Waves broke over their tops.

The coast from Sandy Hook to Deal was pounded by the waves. At Sandy Hook the water rose to the top of the army dock. In High lands the rising Shrewsbury flooded

Byrd Names Coastline For Michigan U. Man

Special to The Chicago Sun.

Ann Arbor, Mich., Dec. 13.—Word was received here today from Adm. Richard Byrd that part of the Antarctic coast line has been named

Volcano Forces Removal Of New Guinea Capital

Lightning Bolt Fells 7 Persons In Alley Pond Park, Queens

Seven persons, two of them women, were prostrated about 5 p. m. yesterday by lightning which struck the ground near by as they sat at tables under a tree in Alley Pond gusts. Most of the picknickers snatched up their lunches and ran for shelter to a refreshment stand a few hundred feet away or to the offices of the Park Department,

Fights 'Swamp' Subdivisions

Action to curb construction

UNIT FIVE

THE CRUST OF THE EARTH

Watch Kilauea

Hawaiians Fear Volcanic Eruption After Quake

HILO, T. H. (AP)—Scientists watched Kilauea volcano for possible signs of eruption today after an earthquake which caused minor damage to some buildings here yesterday.

The quake, described by seismologists as "moderate to strong," oc-

VOLCANIC MUD BURIES TOWN; 500 ARE KILLED

Lima, Dec. 15.—(AP)—Government agencies speeded relief today to the stricken departmental capital of Huaraz, where more than 500 persons were reported to have perished in a tremendous avalanche of water, mud, rocks and volcanic lava

New FHA Land Planning Engineer for Midwest

Mexican Quake Wrecks Colima; Volcano Erupts, Fires Menace City

Schools Will Aid Fight To Conserve City Water

Striking a new note in its water conservation campaign, the Department of Water Supply, Gas and Electricity completed plans yesterday for distributing 1,000,000 pamphlets through the

WORST' QUAKE FELT; EPICENTER STILL A MYSTERY

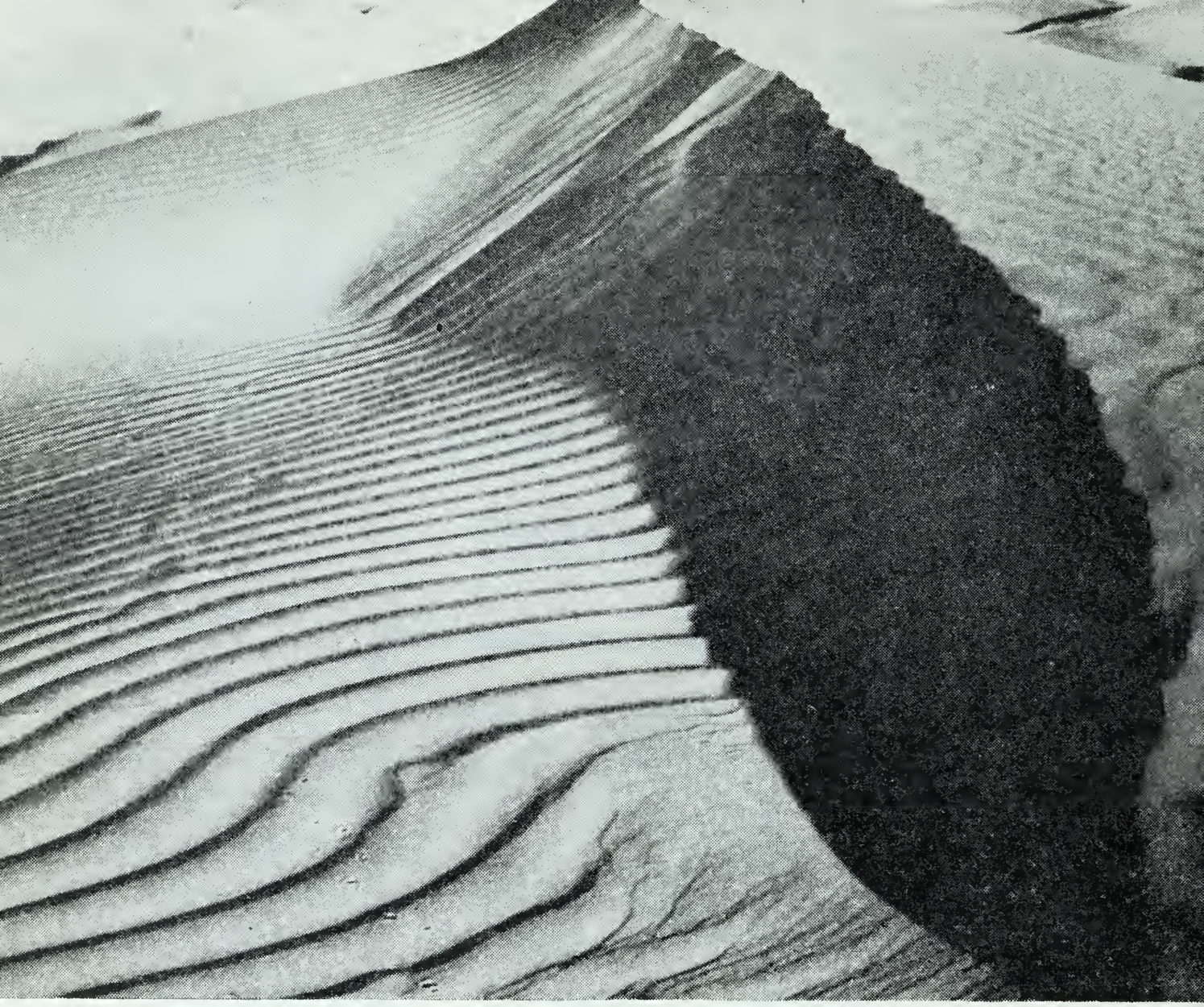
A violent earthquake, which some seismologists said was the greatest

9,000,000 Acres at $5 Bought by U. S. Since '34

WASHINGTON, July 25.—With the payment of the last checks at the close of the fiscal year, the government closed its books on one of the largest land-buying programs it has ever undertaken,

ANNUAL OIL WASTE PUT AT $1,000,000,000

Expert of Resources Board Urges Strict Conservation





Unit Five

THE CRUST OF THE EARTH

Man, the explorer, is ever seeking new worlds to conquer. However, this does not mean that little remains to be learned about the earth itself. Much of the world of discovery with which man concerns himself has to do with the most commonplace things about him.

In a sense the telescope has carried the scientist millions of miles out into space to worlds beyond; on the other hand, he cannot describe with exactness and certainty the nature of the matter which lies a relatively short distance under his feet. When he digs into the earth he usually comes to granitelike rock, and soon the practical difficulties of continuing convince him that knowledge of the earth's interior must be discovered in some other way. Although it would be interesting, and even exciting, to get to the center of the earth, problems relating to our immediate surroundings are the ones that we *must* answer satisfactorily in order to live effectively and successfully.

The "crust of the earth" includes the lower layer of the atmosphere (the troposphere), the upper layer of the solid earth (the lithosphere), and the portions of the earth which are covered with water (the hydrosphere). In this rather limited zone, all of man's activities are carried on. These activities and even man's existence are dependent on the raw materials found in these regions, so much so, in fact, that one author has described the crust of the earth as "the storehouse of civilization." From the crust of the earth come minerals and metals; coal, petroleum and gas; water; and gases of the air. Covering the solid part of the earth is a thin veneer of soil—a natural resource of inestimable value.

Many perplexing social and economic problems have developed in this area because of the unequal geographical distribution of natural wealth. Likewise, there are problems to be solved which result from the work of the weather in promoting erosion and soil losses. This unit deals with some of these problems which arise as man endeavors to use and conserve more effectively the resources available in the crust of the earth.

Photos courtesy U. S. Department of the Interior; Union Pacific Railroad

Problem 1: What agencies modify the crust of the earth?

• THIS CHANGING EARTH

We live in a world which is constantly changing. When attention is called to changes in the earth, you probably think of the violent changes caused by earthquakes, volcanic eruptions, cloudbursts, landslides, and the like. It is certainly true that these produce very rapid and extensive changes. San Francisco was destroyed in 1906 by an earthquake and the fire which followed. Such newspaper headlines as "TOLL IN TURKISH EARTHQUAKE LIFTED TO MORE THAN 42,000" focused attention during December, 1939, upon a similar disaster in another part of the world. A rapid change took place at Yakutat Bay, Alaska, in 1899; the beach was uplifted more than 40 feet during an earthquake. One of the most violent volcanic eruptions ever recorded took place in 1883 on the island of Krakatao in the East Indies. More than two-thirds of the island was blown into the air.

Earthquakes and volcanoes certainly remake the earth's surface in a spectacular manner. However, if we think in terms of the total amount of change produced, they become relatively insignificant. Other far greater but less easily observed movements are continually reshaping the earth's crust. The more important changes take place so slowly that thousands of years may pass before the landscape is greatly altered. It is for this reason that they escape our notice.

Careful observation and measurement show that some parts of the earth's surface are rising and other parts are sinking. The many excellent harbors on our Atlantic seacoast are believed to have formed largely because this coast has slowly sunk, allowing the ocean to move in and "drown" the rivers. The Hudson River is such a "drowned river." Its deep channel extends many miles out into the ocean. There are submerged canyons which scientists believe could have been cut only at a time when this part of the river flowed through dry land. About 100 miles from shore these canyons are 4,000 feet deep; some even surpass the Grand Canyon of the Colorado River in depth and extent. On the other hand, the scarcity of good harbors on the west coast of the United States is thought to be due to the gradual elevation of the coastline.



Erpi Classroom Film

Glaciers probably covered the area of North America shown in white about twenty-five thousand years ago, when the last great southward march of the glaciers occurred.

Great mountains of ice called glaciers have repeatedly spread out from various centers and covered much of the earth's surface at different times in the earth's history. The retreat of the last one of these in North America is responsible for the present slow rising of the area north of the Great Lakes. This land had formerly been pushed down by the great weight of the glacier and is now slowly increasing in elevation. True, the change is slow, but it has been predicted that if it should continue in the coming centuries as it has in those past, Lake Michigan will gradually be dumped like water from a bowl over the present site of Chicago, and the Great Lakes may eventually empty into the Gulf of Mexico by way of the Mississippi River. Thus it is possible that the Great Lakes, which were originally carved out and filled with water by the glaciers, may likewise be destroyed by them. The earth has been undergoing changes like these ever since its birth. Little wonder, then, that civilized man has studied the nature of these changes and has tried to interpret the records found written in the earth's crust.

Who would not like to know how the earth was formed and how it has been changed into what it is today?

• BIRTH OF THE EARTH

No one is certain of when or how the earth was born or of exactly how, after birth, it divided into land and sea. Scientists believe, however, that they have found out much about these ancient happenings. Hypotheses based upon careful observation have been formulated to explain these events, and these afford some of the best examples of scientific problem solving, even though some have proved erroneous. Those which have withstood criticism are believed to be near the truth, although they will probably be modified as more knowledge of the earth is gained.

The famous French astronomer and mathematician, Pierre de Laplace, wrote a textbook in 1796 in which he suggested that our solar system might have developed from condensation within a nebula—that is, an immense cloud of hot gas. During the change from gaseous to liquid or solid state, its rotating motion caused portions to separate as rings from the central mass which was to become the sun. The separated rings formed planets; moons formed from planets by a similar process of ring formation. The hypothesis readily explained the present rings of Saturn—the planet was in the process of forming moons. However, other facts accumulated which the *nebular hypothesis,* as it is called, fails to explain.

After a careful study of the strong and weak features of Laplace's hypothesis, two University of Chicago scientists, Chamberlin and Moulton, at the beginning of this century, advanced what is now called the *planetesimal hypothesis.* It has been as influential during this century as Laplace's was during the last. As in the nebular hypothesis, it is assumed that the entire solar system originated from one mass of material. The parent body, according to this hypothesis, was a star. Our solar system began when some of the hot gaseous material of this star was pulled away from the rest by the force of attraction exerted upon it by another star which came unusually close. The masses which were torn from the star condensed to form the planets, moons, and other bodies of our solar system. What was left of the star after these portions were removed became the center of the system—our sun. In this hypothesis, it is suggested that the planets were not originally as large as they are now but have grown by adding myriads of particles of sun matter which had also been set free and had condensed as separate small bodies, which were called *planetesimals.*

A modification of the planetesimal hypothesis has been formu-

lated by the British scientists, Sir James Jeans and Harold Jeffreys. The *tidal hypothesis,* as it is called, states the belief that gravitation pulled a large amount of matter in the form of a tidal cone away from the sun when another star came exceptionally near to it. Planets formed as the drawn-out mass broke into parts. It differs from the planetesimal theory in proposing that the planets when formed were approximately the same size as they are now.

Although these latter two hypotheses are looked upon favorably by many scientists, it is probable that they will be changed further. Scientists will continue to test them for consistency as new observations are made. Since only the truth is sought, reliable data which would disprove any part of the hypotheses would be as welcome as new data which support them. These hypotheses are the best products to date of scientific reasoning about the origin of the earth. What should your attitude toward them be?

Obviously, our beliefs about the early history of the earth as a separate body will be dependent upon our beliefs as to the preceding process of creation. If it were true that the material composing the earth was originally gaseous, then we would know that a period followed during which much of the gaseous material changed by a process of condensation into the liquid state and that much of this in turn was transformed by crystallization into the solid state.

During the gaseous state, it would follow that much of the earth matter existed as free elements, which for the most part combined during the cooling process to form compounds that became liquid or solid. In this way we could then explain the formation of the first rocks and of the water which covers nearly 71 per cent of the earth's surface.

Today we know that the earth is composed of about ninety-two elements, or fundamental kinds of matter. These have formed various mixtures or have combined chemically in various ways to form the thousands of substances found on earth. A few of the elements have remained free; that is, they have not entered into combination with other elements to form new substances. Thus, gold is an element and is found as such in the earth. Some of the elements are found partly free and partly combined. For example, free oxygen makes up about one-fifth of the atmosphere, whereas combined oxygen makes up by weight about eight-ninths of all water. Most of the elements are found in the combined state. Some elements, such as oxygen, nitrogen, and carbon, pass through cycles. Thus at one time a particle of oxygen may be free in the

atmosphere; some time later it may have combined with carbon to form carbon dioxide; still later it may be part of a plant cell; and still later during the process of food making, the plant may return it to the air as free oxygen.

The history of the earth is much clearer from the time that it became a mass of rock, partially covered with water and surrounded by an atmosphere. The forces which then began to tear down the higher parts and rebuild the earth are still at work, and the history of their past activity can be interpreted from the marks left by them on the earth's crust, as well as from observations of their present activity.

• TEARING DOWN AND BUILDING UP THE EARTH

The sun furnishes the energy that continues the water cycle, which consists chiefly of evaporation, cloud formation, and precipitation as rain, snow, hail, and sleet. By heating the atmosphere unequally and thus bringing about weather changes and winds, the sun becomes responsible for the agencies which tend to level the surface of the earth. The wearing away of the earth's surface by natural processes is called *erosion.*

Water causes more erosion than any other agent. As running streams, ground water, glaciers, and waves, it has helped in the breaking up of rocks to form soil. Water which freezes after flowing into cracks in the rocks is especially effective because water expands as it becomes ice. The pressure caused by the expansion splits and crumbles the rocks. Wind and the expansion and contraction in the rocks due to temperature changes have also helped.

The importance to man of these processes becomes evident when we realize that *all our soil has been formed from rocks.* Soil is simply broken, pulverized, or decomposed rock which has been enriched with humus, the material formed by decaying plant and animal matter.

Unfortunately, the same agents which have helped to form soil may later remove it or make it unsuited for use. In America, water washes out more than three million tons of soil material every year from fertile fields and pastures where it is needed. Some of it is carried to the oceans, but the greater part of it is deposited in stream channels, reservoirs, and other places where it is not needed and certainly is not wanted. Gullies formed by uncontrolled water erosion have ruined one-fourth of Stewart County, Georgia—seventy thousand acres of what was formerly some of the



Science Service

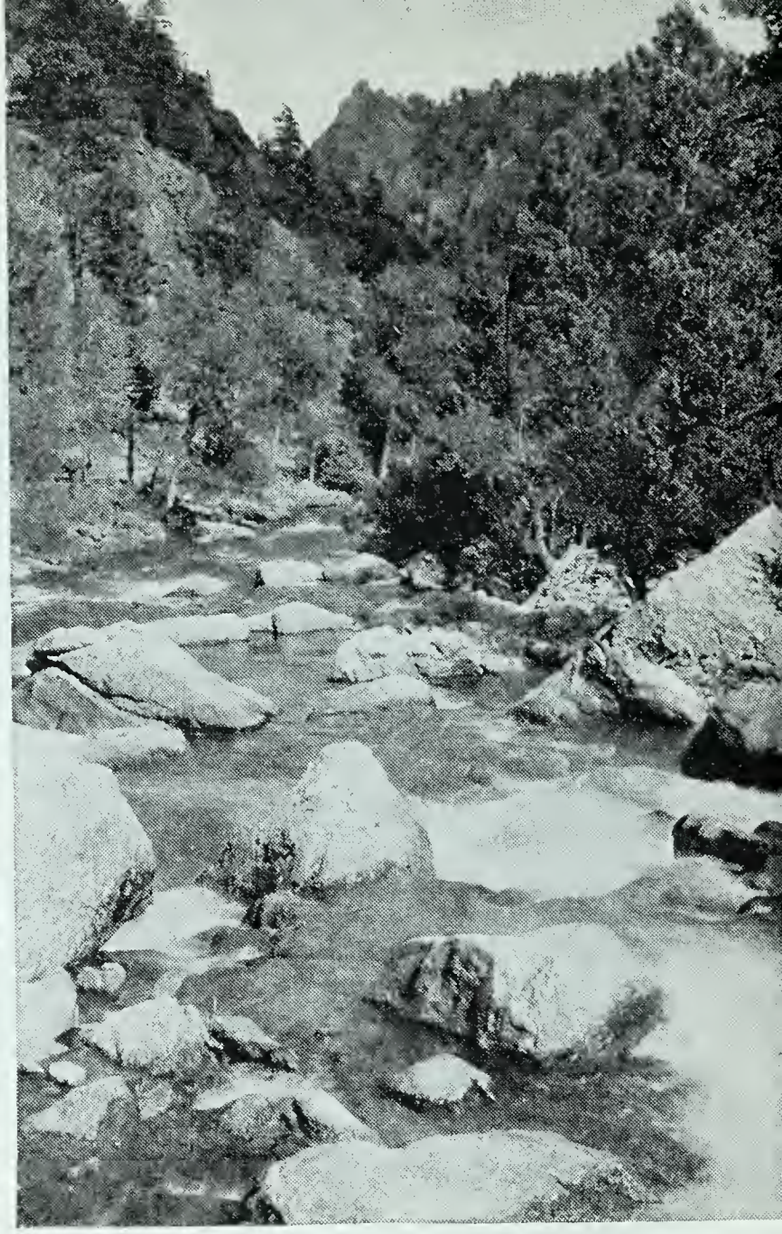
The Stewart County gullies are noted for their enormous size and depth, being from fifty to two hundred feet deep. They have swallowed up good farm land, farm buildings, and highways.

best farm land in that state. Every acre of this land could have been preserved by proper erosion control. All sections of the United States are being damaged to some extent by the erosion of running water. The valley of the Mississippi suffers greatly from such loss of topsoil.

Running water also dissolves soluble minerals as it sweeps over or seeps through the soil, reducing the fertility by carrying away substances which plants need for nourishment. No doubt oceans were originally bodies of fresh water, but they have become salty and are becoming more so as rivers carry dissolved minerals to them. The minerals do not leave by evaporation as water does. One estimate of the earth's age has been made by calculating the number of years that would be required for the rivers to carry to the ocean the amount of dissolved material now found in ocean water.

Rivers carve valleys. Small streams have united to form the rivers and torrents which, in turn, have carved gorges and ravines





Photographs courtesy Glacier National Park (above); Rocky Mountain National Park (top right); U. S. Department of the Interior (bottom right)



Murmuring cascades, rock-strewn beds and V-shaped valleys, and roaring, plunging waterfalls are characteristic of youthful streams.



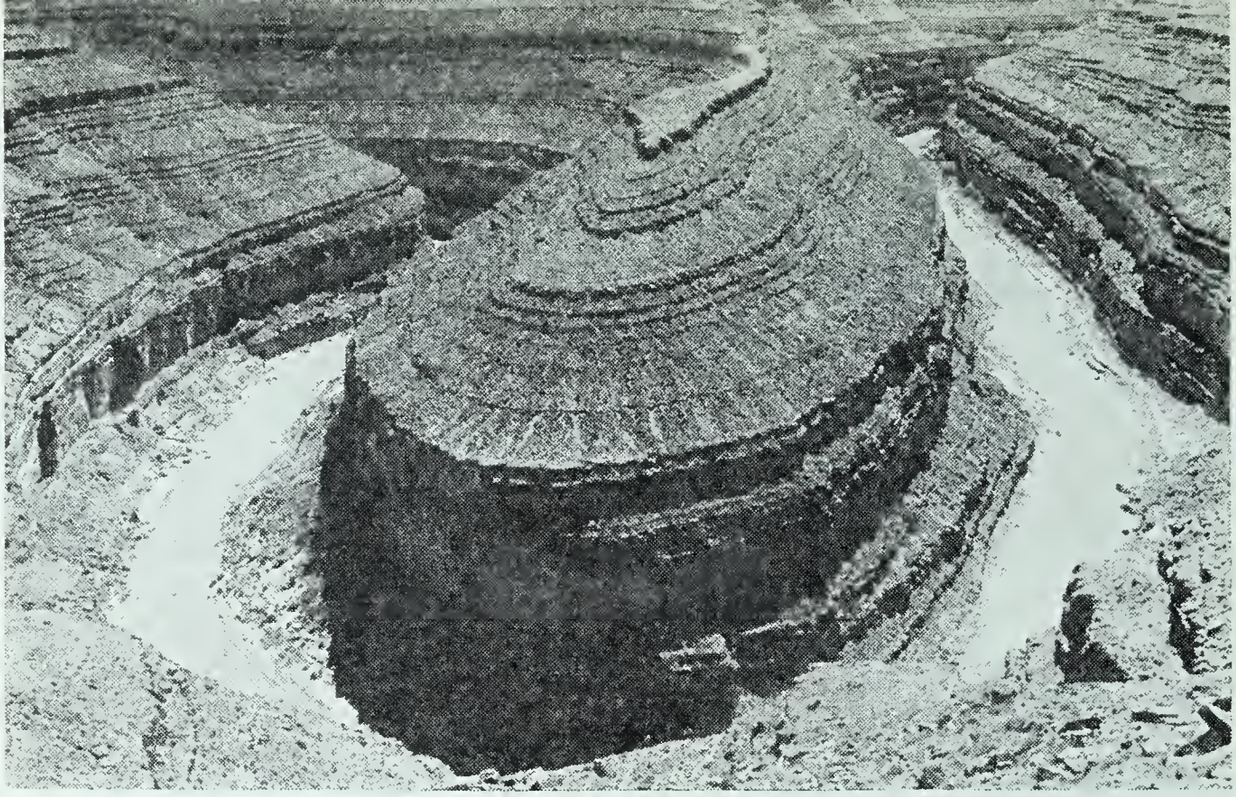


Courtesy U. S. Department of the Interior (top); The Rocky Mountain Parks Transportation Company (bottom)

As a river becomes older, geologically speaking, falls and rapids disappear, and the stream moves more slowly down its valley. Finally, in old age the stream meanders slowly in gentle, sweeping curves through a broad flood plain.

in the rocks. The deepening and widening of these river beds, going on at the same time, has resulted finally in the formation of valleys. Collapse of the river banks, the activities of plants and animals, and the passage of glaciers have helped the rivers develop broad valleys. Sometimes, as amply demonstrated in Arizona, Colorado, and Utah, the downcutting has gone on much faster than the sidewise erosion of the banks, and canyons have resulted. However, most valleys are much wider than their streams.

Geologists believe that rapid streams flowing through narrow, V-shaped valleys or canyons are the more youthful ones. These have not had time enough to widen their valleys. Youthful rivers are likely to have rapids and waterfalls like those of the Niagara River. During succeeding geological eras, such a river gradually shifts its course many times and cuts new channels in its basin.



Courtesy U. S. Department of the Interior

This view of one of the Goosenecks of the San Juan River in Utah shows an old meandering stream that was rejuvenated as the region through which it flows was uplifted. How would you know that this region was once a sea bottom?

The forces of erosion eventually wear down the higher spots and fill in the lower ones. During this process the rapids and waterfalls largely disappear, and the stream then meanders lazily through a broad valley with gently rising slopes. It has then become mature.

About one-third of rain water runs off the land as surface water. Approximately one-half evaporates, and the remaining portion sinks into the earth, becoming underground water which normally reappears in springs and helps to maintain stream flow.

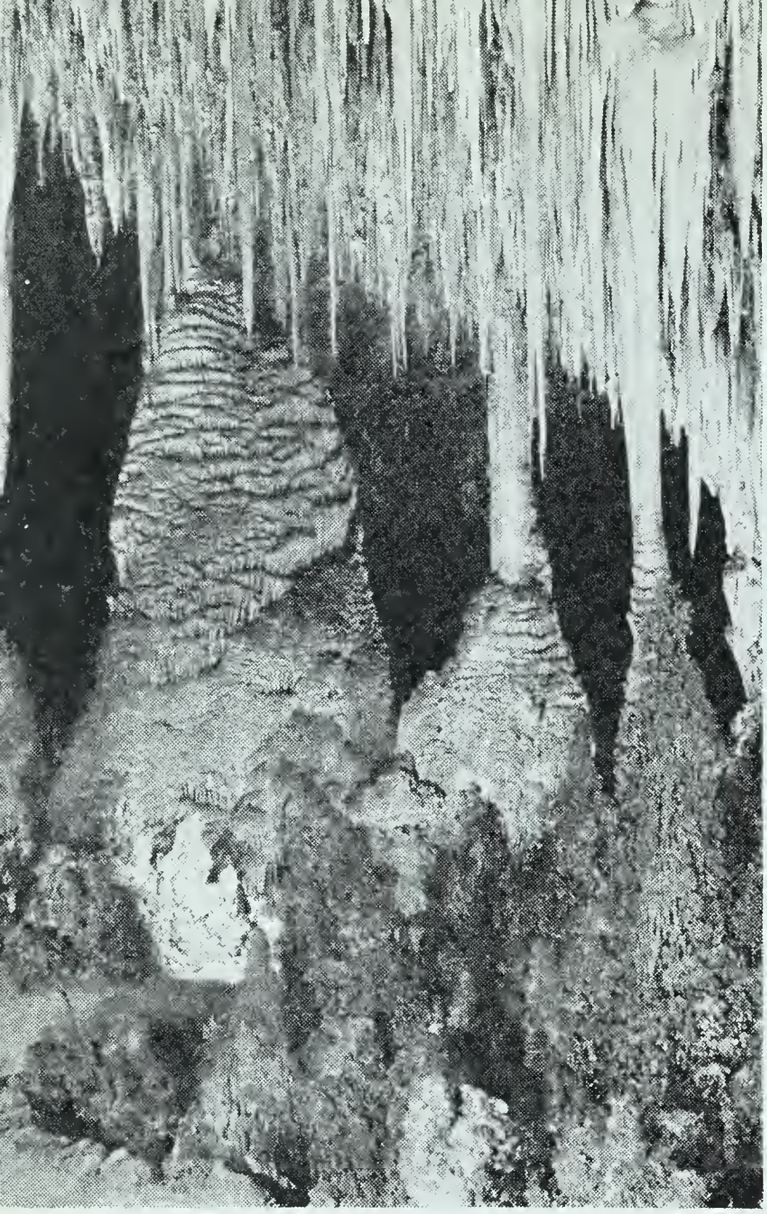
Ground water sinks until it reaches the water table, or level at which all the pores and crevices in the rock or soil are filled with water. It then percolates, or filters, through the soil or rock fractures in the direction of lowest water pressure (in general, toward the valleys), often at the slow rate of only several hundred feet in a year. Wells drilled to a level below the water table can be pumped to yield enough water for a household or even a larger supply.

Water containing carbon dioxide has a dissolving action on limestone, which is insoluble in ordinary water. The carbon dioxide may come from decaying plant material, since carbon dioxide is given off when vegetation decays. This dissolving of limestone by carbonated water is really a chemical process in which a soluble substance is formed from insoluble limestone. Mammoth Cave in Kentucky, the Caverns of Luray in Virginia, the Carlsbad Caverns in New Mexico, and many others as well have been formed by



Courtesy Fred Harvey Transportation Department

The Grand Canyon of the Colorado River to the average tourist is a scene of unforgettable splendor; to the geologist, it is also an open book in which to read a chapter of the earth's history as revealed by the story in the rocks.



Courtesy U. S. Department of the Interior

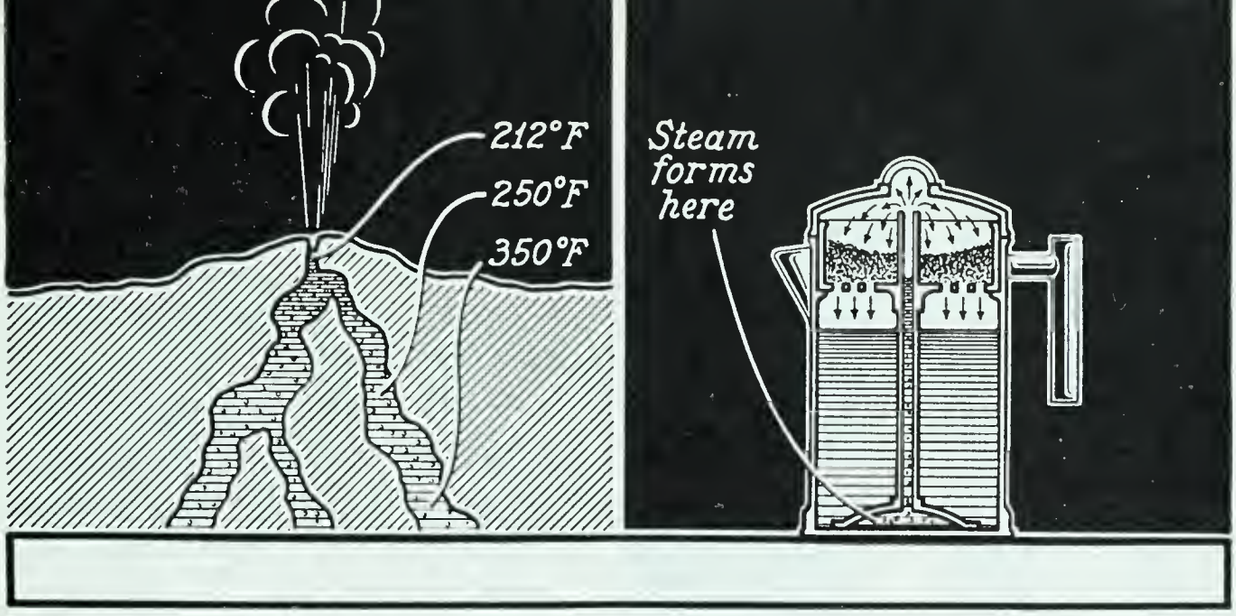
During millions of years, carbonated ground water dissolved and carried away limestone to form the huge Carlsbad Caverns and then partly refilled them with stalactites, stalagmites, and columns.

the dissolving action of water charged with carbon dioxide. In these caverns where water containing the dissolved mineral has dripped from the roof, stalactites form on the ceiling and stalagmites project from the floor. After a long period of growth, a stalactite and a stalagmite may join to form a column. These formations are really made up of limestone which is deposited again by the water as it slowly loses its carbon dioxide in the open cave. Millions of years have been required to form these caverns.

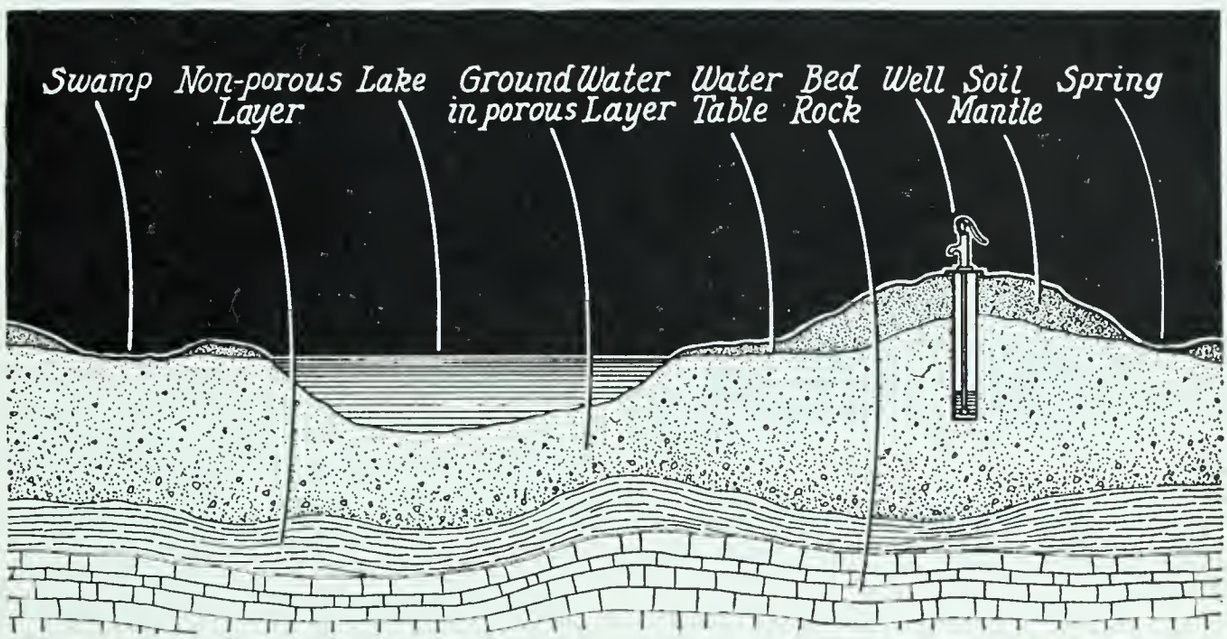
Springs appear when the water table becomes unearthed by some form of erosion. The water in such springs may contain a variety of substances dissolved from the ground through which it flows. Such water is often bottled and sold with various claims made about its value in the treatment of diseases. The American Medical Association has printed the following statement on the cover of one of its bulletins:

> "Mineral waters possess no mysterious or occult virtues in the treatment of disease. No mineral water will be accepted by the medical profession for alleged medicinal properties supported only by testimonials from bucolic statesmen and romantic old ladies."

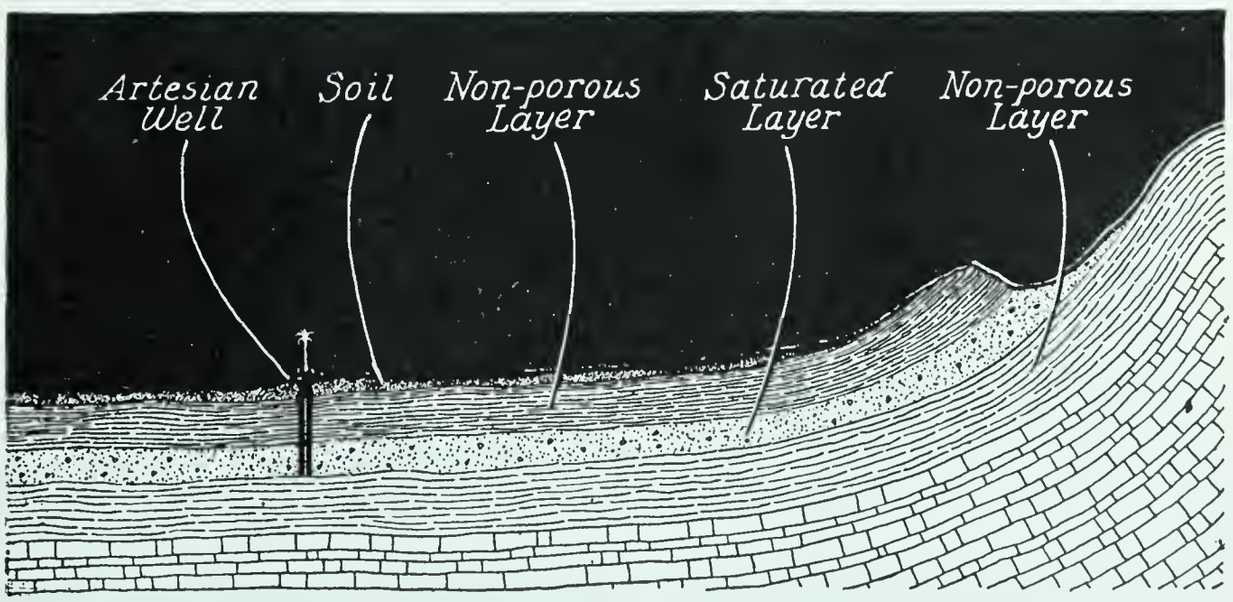
Analysis shows that these waters contain substances whose properties have long been well known to chemists and physicians. Cases are recorded where companies have been fined for fraudulently representing mineral water as a specific cure for various ills such as diseases of the stomach, liver, and kidneys and as being



How is the action of the geyser similar to that of the coffee percolator?



Water sinks into the earth until it reaches nonporous rock. When the surface of the water layer, called the water table, becomes unearthed, swamps, lakes, and springs may form.



How does an artesian well illustrate the principle that water seeks its own level? The distance between the well and the point where the porous layer reaches the surface may be hundreds of miles.



Courtesy The Geological Survey; photo by N. H. Darton

Under what conditions might an artesian well such as this one stop flowing?

effective in the treatment of diabetes, Bright's disease, gout, and rheumatism.

Water which penetrates deep into the hot interior of the earth's crust may have its temperature and pressure greatly increased. Under these conditions the solvent action of water is greatly increased, and it can dissolve abnormally large quantities of minerals. When such mineral-laden water reaches the surface as a spring, its temperature and pressure fall, making impossible the retention of much of the mineral. Deposits form as the solids pass out of solution. They are often beautifully colored and consist of such substances as borax, alkalies, epsom salts, and other salts, some of which are poisonous.

Sometimes the hot underground water collects in cracks or cavities in the rocks. The combination of high temperature and suddenly decreased pressure causes steam to form deep within the accumulated water, and the new pressure thus built up hurls the water from the crevice with explosive force. The same process may be repeated regularly, as at Old Faithful Geyser in Yellowstone National Park, where a column of water is thrown hundreds of feet into the air about every sixty-five minutes.

When a well is sunk into an underground stream which is under high pressure, the water may be forced to the surface in a continuous flow. Such wells are called artesian wells.

Lakes and swamps appear when portions of the land sink below the level of the water table. The great weight of glaciers has sometimes caused land to sink. Other changes in the earth's surface, such as the damming of a valley by rocks and soil from a melting glacier, may also produce lakes. Lakes having no drainage outlets become salty because of the evaporation of water and the accumulation of mineral salts. Most lakes do not become salty, for

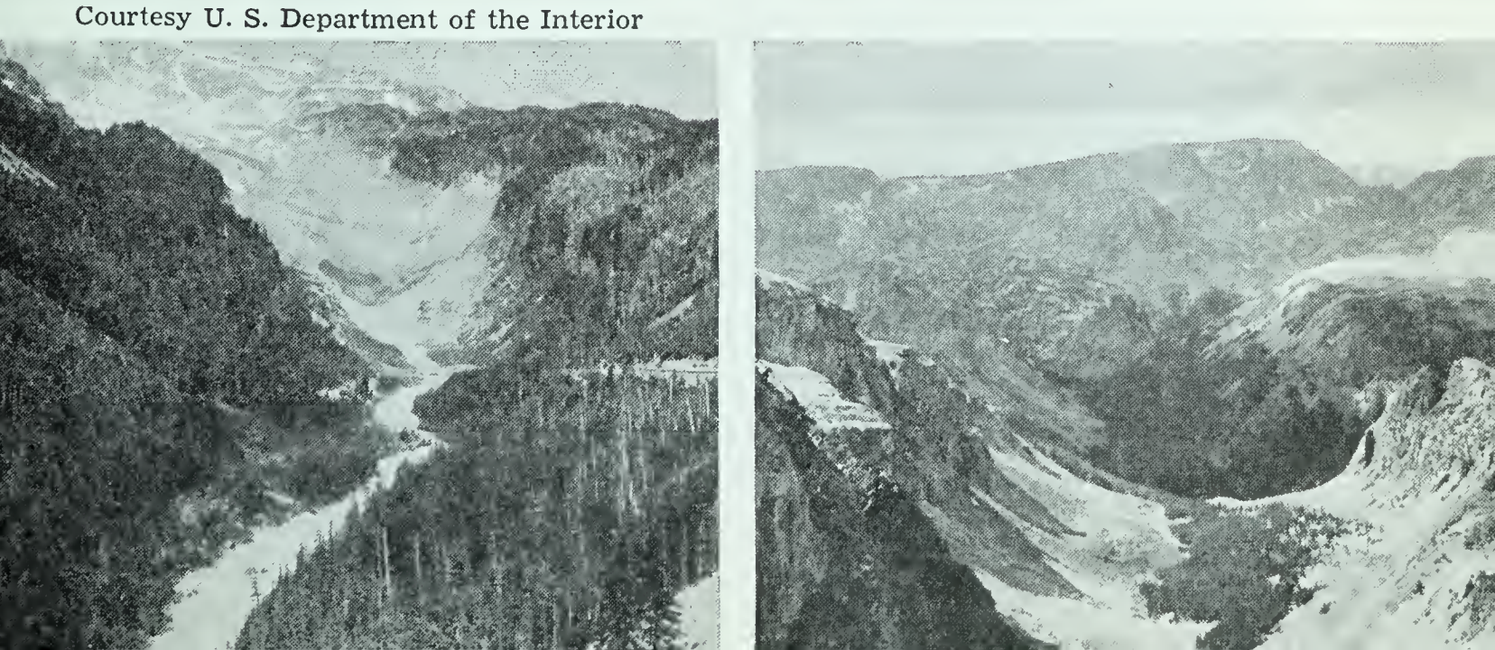
they have outlets through which the dissolved material is lost. From a geological viewpoint, lakes are short-lived, since erosion gradually fills them with solid material; they become shallow and finally disappear.

Great ice sheets at different times during the earth's history have spread out from various centers and covered large parts of the earth. They form when winter snows do not completely melt in the summer and pile up year after year. Some mountain peaks are always covered with glaciers. The heat of the sun and pressure due to the weight of the snow cause melting; subsequent refreezing produces ice. During the time between advances, the ice sheets or glaciers retreated because of faster melting when, for unknown reasons, the climate became warmer. The last and greatest ice age is thought to have occurred about twenty-five thousand years ago. Greenland and the antarctic are still buried with remnants of glaciers which once covered four million square miles of our continent, as well as much of Europe. Near its center, the present icecap covering Greenland is about eight thousand feet thick. This gives an indication of the thickness of snow and ice which once covered Canada and a large part of the United States. The glacier reached farthest south in the Mississippi Valley, extending to the point where the Ohio River joins the Mississippi River. East of the Mississippi, its lower boundary followed the direction of the Ohio River northeastward toward New Jersey and thence across Long Island.

Glaciers modify the land over which they pass by their scouring action and by leaving earthy deposits as the ice melts. The scouring action of a glacier is caused by its movement. Even though it is solid, ice slowly flows as great pressure acts upon it. The pres-

Contrast the V-shaped river valley at the left with the U-shaped glaciated valley at the right.

Courtesy U. S. Department of the Interior







Photos courtesy Northern Pacific Railway

The face of this glacier, a lofty wall of ice, is reflected in the lake formed by the melting of the ice mass in July and August.

These markings on the wall of Glacier Creek Canyon in Montana are mute evidence left by a glacier many thousands of years ago.

sure which causes the ice flow in glaciers is caused by gravity, that is, by the weight of one layer of ice upon another. A glacier may move an inch or many feet a day depending upon such factors as temperature, slope of the land, smoothness of the rocks beneath it, and the thickness of the snow and ice. The rocks which it drags along increase its scouring action. V-shaped valleys formed by the erosion of rivers become U-shaped as glaciers pass through them. Mountain peaks which formerly rose into pinnacles become rounded and dome-shaped under the grinding action of glaciers. This accounts for the typical New England scenery with its U-shaped valleys and dome-shaped hills and mountains.

These potholes were drilled into solid rock by plunging water and whirling stones during the passage of the great ice sheet.



Among the best reasons for believing that glaciers have marched over the face of the earth are the scratches and furrows found on the surfaces of rocks in glaciated regions. In any particular region the glacial scratches and furrows point in one general direction, thus indicating the direction along which the glacier advanced. "Glacial erratics" are common in regions passed over by glaciers. These erratics are boul-



Emmons Glacier, on the eastern slope of Mount Rainier, is the largest glacier in continental United States. Mountain glaciers like it . . .



. . . gouge out U-shaped valleys as they move down the mountain slopes . . .

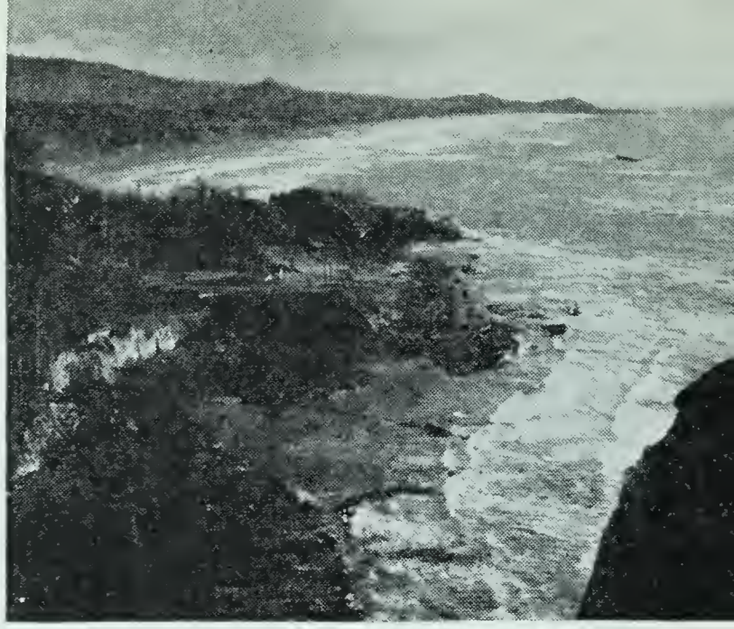


. . . and leave glacial boulders, or "erratics," strewn over the landscape as evidence of their former presence.

Photos courtesy U. S. Department of the Interior



The pounding surf . . .



. . . eats away at the mainland . . .



. . . producing jagged shorelines and islands of resistant rocks and treacherous currents . . .



. . . and giving us the majestic beauty of the rugged, "rock-bound coast of Maine."

Photos courtesy U. S. Department of the Interior

ders which are frequently different in composition from the bedrock upon which they rest. Some of them are so large that a glacier is the only known agency that could have transported them. It is ordinarily possible to travel in the direction from which the glacier advanced, as indicated by the glacial scratches, and to locate the area where the bedrock has the same composition as the glacial erratic. What conclusion would you draw from this? Here again we see the usefulness of a hypothesis in explaining how the earth has come to be as we find it today.

When a glacier flows faster than its front melts, it continues to advance; when the melting becomes faster than the rate of flow, it begins to retreat. The accumulation of earth, stones, and other



Acme

This bluff is slipping into the sea. Note the crumbling roadway and the foundations of homes that have been moved away as the bluff continued to slide toward the sea.

debris that the glacier carried with it is left in a ridge at the edge as the ice melts. Such ridges are called *moraines.* Lakes form as water from melting ice is held between these moraines and the retreating glacier. The Great Lakes, Lake Winnipeg, and thousands of smaller lakes in Canada, Minnesota, Wisconsin, and Michigan began when water was trapped in this manner.

Marine erosion is constantly changing the shorelines. Rivers slowly fill the bays with silt and clay; the pounding of the waves cuts back the projecting headlands. Thus erosion tends to make shorelines less uneven after long periods of time. However, other disturbances cause the shores to rise or fall and counterbalance the effects of erosion. Scientists believe that the fraction of the earth's surface covered by water has remained fairly constant for millions of years.

Other agencies modify the earth's crust. Changes in temperature have a very destructive effect on rocks because of irregular expansion and contraction. A piece of glass that has been heated cracks when cold water is thrown on it because the cooled part contracts and pulls itself away from the portion which has not been chilled. The glass is also likely to break during the initial heating because of the strains caused by unequal expansion. Similarly, alternate heating and cooling that occur from day to day cause uneven expansion and contraction in rocks, thus giving rise to forces which cause them slowly to break and crumble.

Winds carrying dust or sand have great wearing effects upon the surfaces against which they blow. Their action is greatest in dry, desert regions. Automobiles have had their paint removed and their windows etched when caught on deserts during a sandstorm. The scouring effect on landscapes is the same as that of the sandblast used to clean castings in steel foundries or to clean old stone buildings.

Some of the most harmful work of the winds takes place on farms where rainfall is rather slight. Much farm land on the western plains of the United States was destroyed during the great dust storms of 1934 and 1935. Valuable topsoil loosened by plowing was blown away, some of it as far east as the Atlantic coast.

• BENDING, FOLDING, AND BLOWING UP THE EARTH'S CRUST

If given time enough, the agents and forces of erosion acting alone and unchecked would wear down the land areas of the earth and fill in the ocean basins, so that the earth would become a globe



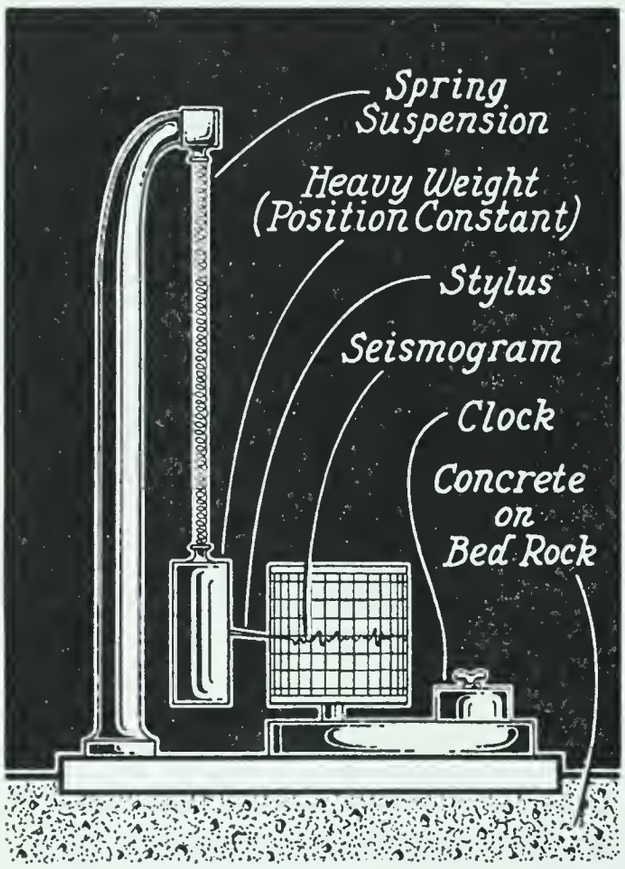
Ewing Galloway

This photograph of a "sinking canyon" in Idaho shows what is likely to happen when slippage occurs along a geologic fault. Earth movements along well-established fault lines cause most earthquakes.

entirely covered with water. This has not already happened and is unlikely to happen, because movements in the earth's crust counterbalance the tendency of erosion to level the earth's surface.

Observations indicate that several thousand earthquakes occur each year. Most of them are very slight tremors. In spite of their frequency, we seldom experience earthquakes, because most of them occur in definite zones of the earth far removed from the greater part of the United States. However, our west coast does lie in an earthquake belt which borders the Pacific Ocean. Another such zone stretches through the Mediterranean eastward to Asia.

People once thought that earthquakes were a punishment sent by the gods. With the growth of the spirit of inquiry and the spread of scientific information, men learned that earthquakes are really "shivers" or vibrations passing through the earth. They are caused by slippage within the rocky portions of the earth's crust. Under terrific pressure, rocks become elastic, bend, and slowly flow. Sudden crushing effects or prolonged bending may finally lead to the breaking point, so that fractures form in the rock layers. If the rock on one side of the fracture slides over that on the other side, a condition known as a *fault* is produced. Most earthquakes occur when rock layers break or slip along fractures already present. Sudden movements take place at these times. The earthquake belts exist in the regions where the stress in the rocks is so great that fractures and subsequent faulting occur. The California earthquake which resulted in the destruction of San Francisco in 1906 was caused by a movement in the San Andreas fault. This fault extends for several hundred miles near the coast line and makes



Very sensitive seismographs indicate that the earth is trembling most of the time.

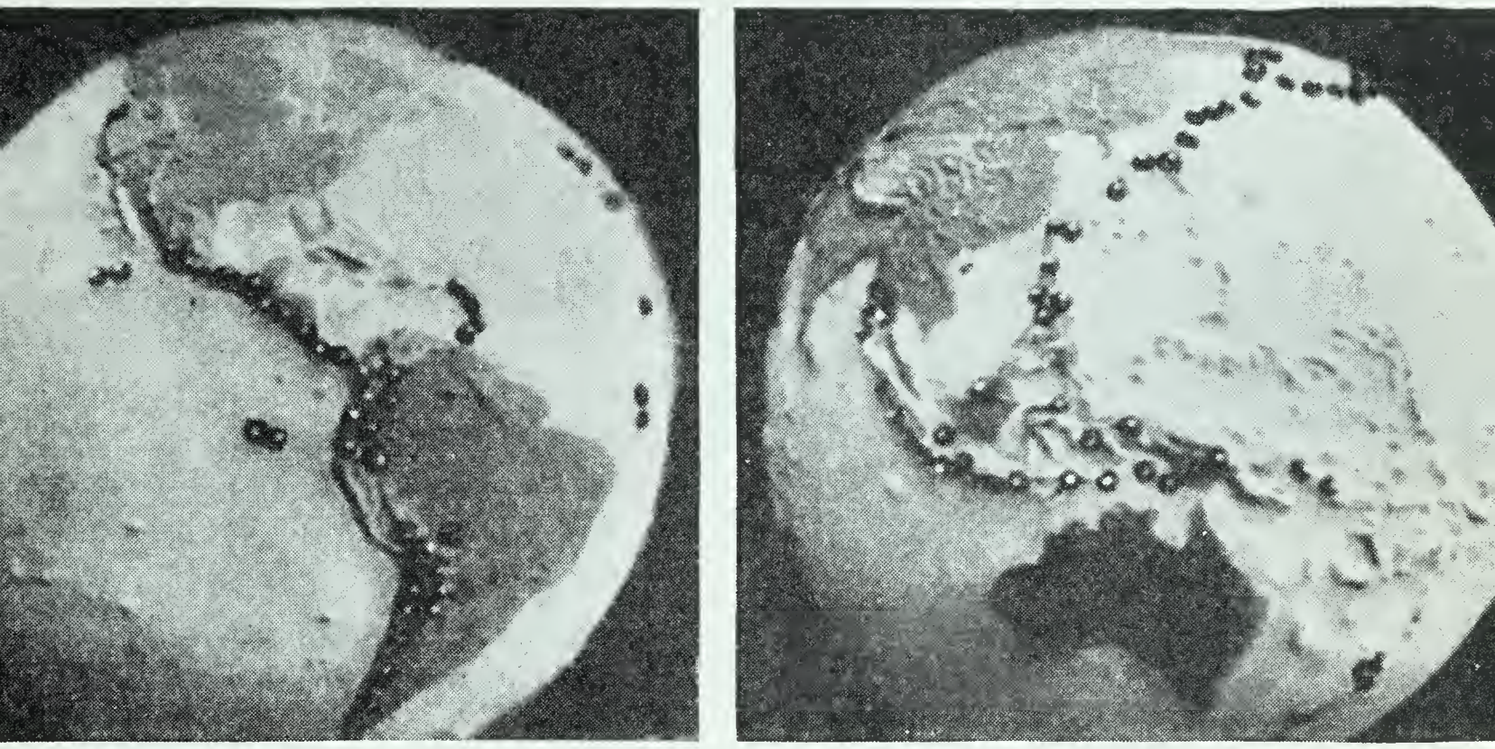
this region particularly subject to earthquake disturbances. In the construction of dams, tunnels, and water passageways in mountainous regions, engineers rely on the findings of geologists who determine whether the region contains faults which would make the proposed construction inadvisable.

One of the most destructive earthquakes experienced in the United States damaged or destroyed nearly all of the buildings of Charleston, South Carolina, in 1886. Twenty-seven persons were killed. It was felt in most of the eastern states.

Japan suffers earthquakes more often than any other country, averaging about three a day. The great Japanese earthquake of 1923 destroyed billions of dollars worth of property and resulted in the deaths of nearly 150,000 persons. The Netherlands East Indies and India also have frequent earthquakes. Fortunately, most of them are not severe and do little or no damage to buildings and other structures.

The explosion of volcanoes has at times caused less extensive earthquakes. Thus in 1888, when Bandai-san, in central Japan, erupted, an earthquake was felt over an area of twenty-five miles. Other movements such as landslides on mountain slopes or the collapse of the roofs of caverns may also cause earth tremors.

The seismograph detects and records earthquakes and earth tremors. This instrument makes use of a principle with which everyone is acquainted. When you are standing in a bus which is stopped suddenly, you may have to grab quickly for some support to keep from falling. The physicist points to this an an illustration of *inertia*—the tendency of objects to remain at rest or in motion unless acted upon by some outside force. Inertia prevents instantaneous starting or stopping even when the new force has begun to act. We momentarily tend to remain stationary when the



Erpi Classroom Film

Volcanoes form a ring of fire around the Pacific Ocean.

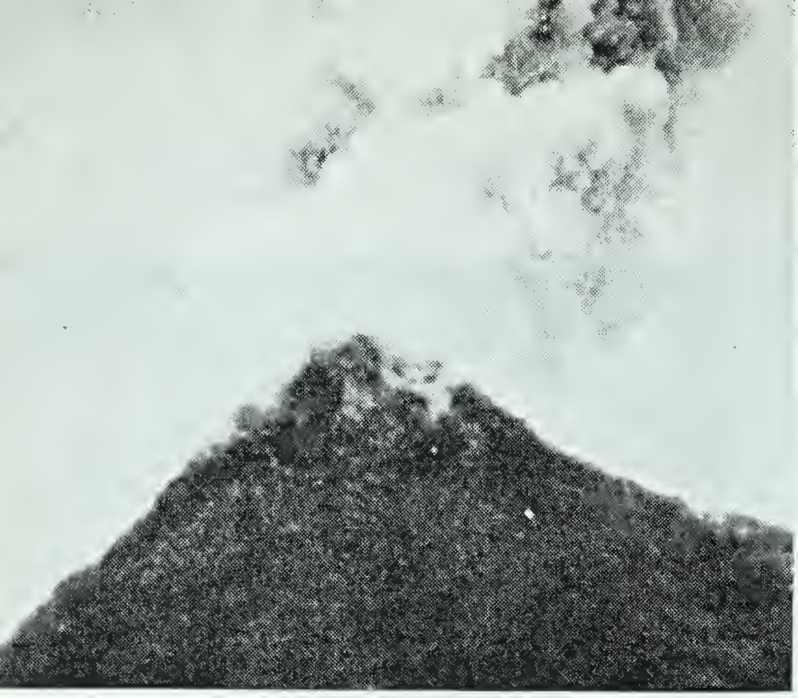
bus starts to move and consequently tend to fall backwards. When the earth suddenly quakes, there is a similar lag before objects on its surface tremble with it.

The pendulum is the most useful device for using this lag to indicate earth tremors. Nearly all seismographs contain a pendulum. The pendulum support moves with the earth during a quake, because the structure to which it is attached is imbedded in the earth. Due to inertia there is a slight delay before the pendulum bob moves from its position of rest. If a point or stylus were attached to the pendulum bob, it could be made to record this movement on smoked paper placed under the point. We would then have a crude form of seismograph.

Commercial seismographs often employ horizontal pendulums mounted on two supports much like a gate. They have provision for magnifying the pendulum movements by a system of levers before the record is marked on smoked paper by a stylus. Sometimes a mirror is used instead of a stylus. Light is arranged so that it falls upon the mirror, and the reflected ray is photographed.

Very sensitive seismographs indicate that the earth is trembling slightly most of the time. Several thousand earthquakes occur each year. When violent, they are the most terrifying of natural occurrences.

Volcanoes occur in the greatest number in the same general



Erpi Classroom Film

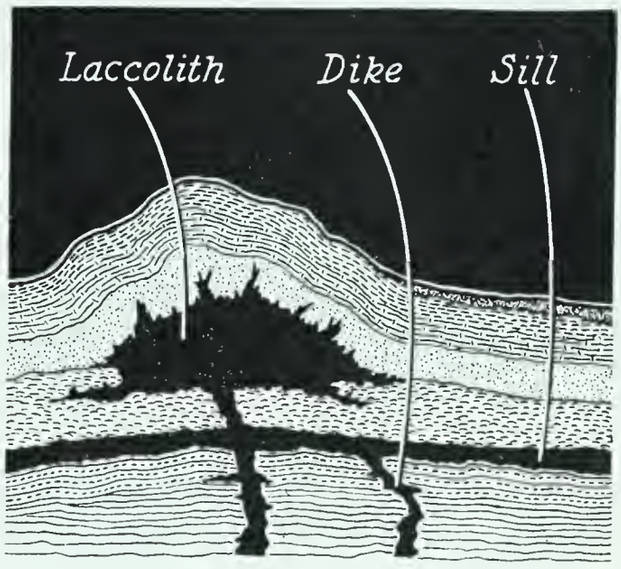
The hot lava sometimes bursts torth at the mouth of a volcano with explosive force.

regions as do earthquakes. They are distributed principally around the shores of the Pacific Ocean and in the region extending from the Mediterranean eastward to India, Burma, Thailand, and the Netherlands East Indies. The only active volcano on the United States mainland is Lassen Peak, California, and its action is quite feeble. In former geological times, Mount Rainier, Mount Hood, and many other western peaks belonged to the list of active volcanoes encircling the Pacific.

An examination of the causes producing volcanoes makes it appear logical that earthquakes and volcanoes should be found in the same regions. Experience with mine shafts and other borings into the earth's crust indicates that the interior of the earth becomes hotter as greater depths are reached. The heat at great depths would be sufficient to melt the rocks if the pressures at these depths were not great enough to prevent this change from solid to liquid. The fractures in the rocks of the earthquake belts relieve the pressure upon portions of this heated interior, and the expanding material becomes liquid and gaseous. Driven by the pressure of the gas, the molten liquid escapes through the fractures in the rocks and sometimes bursts forth at the surface with explosive force. Fragments of rock and earth from the top of a mountain may be hurled into the air during the first surges of lava. As the debris falls back again about the opening, it builds the typical volcanic cone.

In past times, volcanoes, like earthquakes, have been very destructive. Volcanoes may continue to erupt for days, months, or even years. Eventually they all become inactive. The greatest active craters are found in the Hawaiian Islands; in fact, the islands are merely the tops of volcanic structures which have been built up from the floor of the Pacific Ocean—perhaps thirty thousand feet deep in that region—until they project above the surface of the water. The most explosive of volcanoes is Krakatao, situated on a small island near Java. After being quiet for about two hundred years, it exploded in 1883, blowing into the air two-thirds

of the island, which formerly had an area of twelve square miles. Waves, which were created as the sea filled in the gaping crater, rushed upon the lower parts of Java and Sumatra, killing between thirty thousand and forty thousand inhabitants. Fine dust from the volcano circled the earth several times while settling and for three years caused unusually red sunsets.



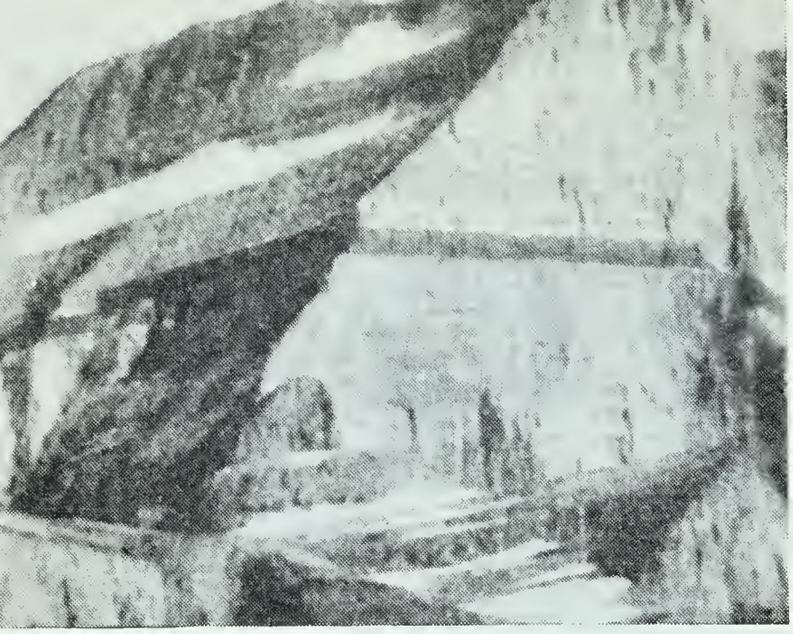
A lava flow failing to reach the surface of the earth forms a solid underground deposit.

Volcanic eruptions sometimes occur beneath the sea. In 1831 such a submarine volcano formed a new island in the Mediterranean Sea. Graham's Island, as this island made of cinders was called, did not last long, because wave erosion soon reduced it to a shoal. The Aleutian Islands off the coast of Alaska have many active volcanoes. Bogoslof, for example, is really only the top of a large volcano. Its frequent eruptions periodically change the shape and size of the island.

In some regions, outflows or extrusions of lava have occurred from cracks in the earth's crust. These are called *fissure eruptions.* In 1783, a fissure eruption took place in Iceland from a crack in the earth twenty miles long. Lava overflowed on both sides of the fissure as far as forty miles from the opening. The broad plains or plateaus of the Columbia and Snake rivers in our own northwestern United States are believed to have been formed by the erosion of an outpouring of lava. This great lava sheet covered 150,000 to 200,000 square miles to a depth of 3,000 feet in some areas.

Lava that has solidified on the earth's surface has the appearance of either glass or stone. When the lava cools rapidly, it solidifies before the individual minerals have had much opportunity to crystallize and takes on a glassy appearance. When the cooling is slower, crystallization of the minerals occurs, the lava becomes stonelike, and the individual particles can be detected. *Basalt* is a typical rock formed from lava as it cools at the surface of the earth.

A lava flow failing to reach the surface of the earth forms a solid underground deposit. In this case it is called an intrusion rather



Erpi Classroom Film

The horizontal dark band is a volcanic intrusion called a sill. How would you explain its formation and present location?

than an extrusion. Intrusions are coarser grained than extrusions, since the crystals grow larger during the slower cooling that takes place beneath the surface of the earth. Large, deep-seated intrusions of lava are called *batholiths.* When lava intrudes into cracks in the neighboring rocks, it forms what geologists call *dikes* and *sills.* Dikes are intrusions which cut across the beds or layers of the older rocks, and sills are intrusions which run parallel to the layers of rock which they have invaded. If a sill raises the overlying layers to form a large dome, the formation is then called a *laccolith.*

Mountains have been built in the past and are being built today by comparatively slow processes. It was once thought that mountains were wrinkles formed in the earth by contraction as the crust cooled from a molten condition. Scientists have discarded this hypothesis, because such cooling could account for only a small part of the folding that has occurred in the earth's surface. Moreover, they are not sure that there has been much cooling since the rocks were first formed.

Pressure tends to crowd material into the least possible space. The material comprising the earth itself is placed under great pressure by the force of gravity. One estimate places the pressure roughly at forty-five million pounds on each square inch near the center of the earth. Rearrangements of the various materials take place as this great pressure tends to crowd them into less space. Solids actually flow, although slowly.

Most of the force is directed toward the center of the earth, but sidewise forces also develop in the crust as some substances yield to the pressure more readily than others. This horizontal push wrinkles the surface into mountain ranges wherever it becomes so great that the rocks cannot resist it. Since softer materials accumulate most rapidly near the edges of continents where rivers and waves deposit the products of erosion, here, as would be expected, the greatest wrinkling usually takes place. Thus mountain ranges are commonly found along the margins of continents, more or less parallel to coast lines.

A condition of equilibrium would eventually be reached and mountain-building would stop but for the upsetting influence of erosion. Even while mountains are being formed, erosion begins to tear them down and to transport the eroded material to the valleys below. It thus decreases the weight over the mountain area and increases it over the valley area. Rock movements take place again in order to restore equilibrium among the pressures. Valleys sink and the elevated portions are pushed even higher. Thus mountain ranges are continually torn down and rebuilt.

The *theory of isostasy,* as this weight-balancing theory is called, gives us a logical explanation for the rising and sinking of the land in various areas. Geologists easily account for the present rising of the land above the Great Lakes by calling attention to the decrease in weight over this area as the glaciers have melted. According to this theory, it seems reasonable that the total amount of sinking and rising should be about equal. Hence the amount of land covered by water should theoretically remain almost constant, as it does in fact.

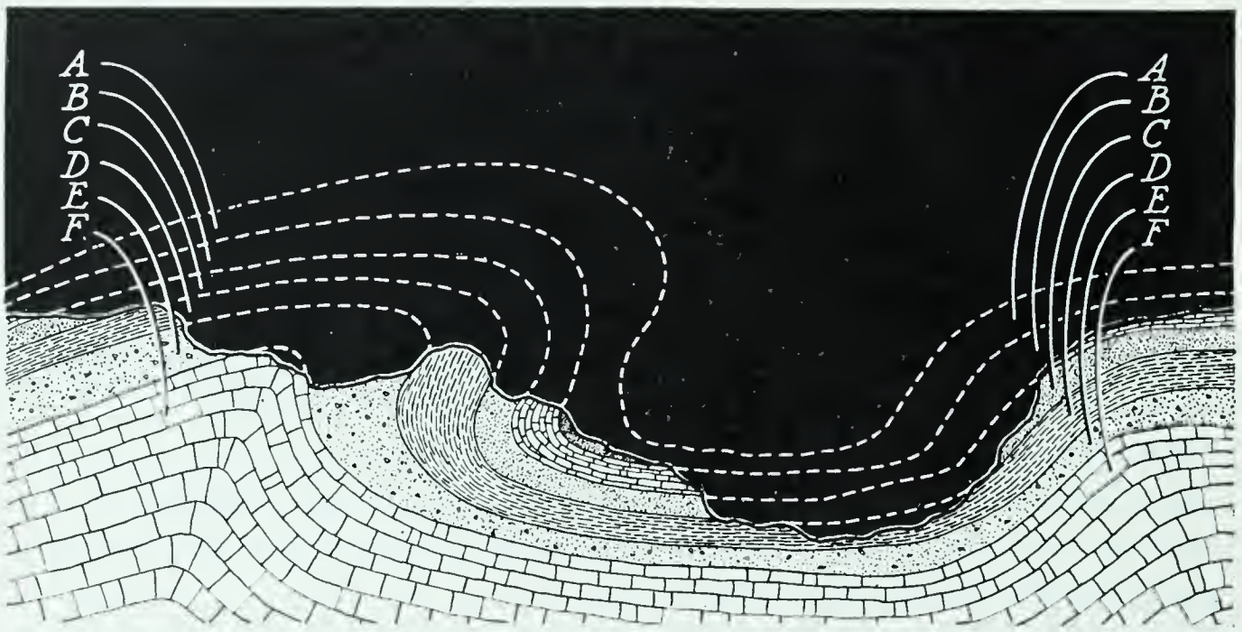
• HISTORY OF THE EARTH

Man has been able to penetrate but a short distance into the earth's crust. The workings of one of the Crown mines on The Rand, the gold fields in Transvaal, Union of South Africa, are 8,530 feet in depth; the workings of a gold mine in Brazil are 8,140 feet in depth. The world's deepest oil well, in California, is 15,004 feet deep. Erosion has helped man unravel the story of the earth by exposing rocks which were once buried as deep as five or ten miles. These distances, however, make up a very small part of the four thousand miles to the center of the earth. Consequently, whatever man learns

The igneous rock composing the dike resisted the eroding force of the river longer than the softer rock through which the river made its way ages ago.

Courtesy Canadian National Railways





The dotted lines represent a reconstruction of a section of the earth's crust as it was thousands of years ago based upon observations of its present structure. How many conclusions can you draw from the data represented by this reconstruction?

about the interior of the earth must be gained by some other method than direct observation.

By indirect methods much has been learned of the earth's interior. It is known to be hot, because volcanic materials coming from it always have very high temperatures. Thermometer readings in mines show that the temperature of the earth steadily increases as the depth becomes greater. The average increase is about one degree Fahrenheit for each sixty feet one descends.

If the earth's temperature continues to increase at this rate, near the center it must be above the melting point of rocks found at the earth's surface. Is, then, the interior of the earth in a melted condition? Scientists are quite sure that the earth's center is solid and not liquid, because earthquake waves which pass through it would not pass through liquids with the high velocities that have been recorded. In addition, they know that the great pressures in the interior of the earth would tend to keep the earth material solid even though the temperature is very high.

Study of the weight and volume of the earth indicates that the average weight of a cubic foot of the earth is much greater than the weight of a cubic foot of material taken from its surface. Scientists are convinced that the nature of the material changes as the center is approached. Many believe that the core of the earth is made of a mixture of nickel and iron. This view is sup-

ported by the fact that the cores of meteorites which fall to the earth are principally iron and nickel. These are the materials left when the outer layers of the meteorite have been burned off.

Many different methods have been used to estimate the age of the earth. Bishop Ussher, after a study of the sacred writings, announced in 1654 that the earth was then 5,658 years old. This placed the birth of the earth in the year 4004 B.C. Albert Einstein places its age at ten billion years. Some scientists have calculated the length of time that would be required for the rivers of the earth to deposit the amount of salt found in the oceans; others have decided how long it would take for the thick layers of sedimentary rocks to be formed; others have turned to astronomy and the hypotheses of the earth's origin for their data. Although the results differ, *all methods based on studies of the earth itself agree that our planet is very old and that its age must be stated at least in millions of years.*

The discovery of radium and radioactive elements led to a new method of computing the earth's age. This is believed to be more accurate than any other. The chemical element uranium constantly casts off particles and changes into another element, lead. By very reliable methods, physicists have determined that *half of any piece of uranium would make the change into lead in approximately five billion years.* Since the highest lead-to-uranium ratio found in the rocks is approximately 0.4 to 1, this method estimates the earth's age at $0.4 \times 5{,}000{,}000{,}000$, or 2,000,000,000 years. It must be remembered that this approximation is simply what appears to be the most accurate scientific estimate of the earth's age and may, of course, be subject to error. Moreover, this age takes us back only as far as the formation of the first rocks. Perhaps, as astronomers suggest, another billion years or more may have elapsed in the earth's history before the first rock formations came into existence. In any case, the most accurate method of estimating the earth's age places it at a minimum of two billion years.

Geologists have divided the eartn's history into large units called eras and smaller units called periods. The eras have been named according to the animal and plant life believed to have existed at the time.

The following outline summarizes the important events and changes that scientists believe have taken place during the earth's history:

BRIEF HISTORY OF THE EARTH

I. Archeozoic era (primitive life)
Igneous and metamorphic rocks. No distinct fossils. Geologic history obscure.

II. Proterozoic era (early life)
Scanty fossil record of primitive invertebrates and algae. Earliest known glaciation.

III. Paleozoic era (ancient life)
Cambrian period. No land animals. Trilobites and brachiopods.
Ordovician period. Complex trilobites. First simple fishes.
Silurian period. First known land plants. Eurypterids (giant scorpions). Crinoids (sea-lilies).
Devonian period. Age of fishes. First amphibians.
Carboniferous period. (Usually divided into the *Mississippian* and *Pennsylvanian periods.*) Age of amphibians and giant insects. Coal forests.
Permian period. Primitive reptiles. Severe glaciation.

IV. Mesozoic era (middle life) "Age of reptiles"
Triassic period. Rise of dinosaurs. Primitive mammals. Cycads and conifers.
Jurassic period. Pterodactyls (flying reptiles) and first birds.
Cretaceous period. Extinction of dinosaurs at end of this period; among them were the largest land animals that ever lived. Spread of flowering plants and modern insects.

V. Cenozoic era (recent life) "Age of mammals"
Tertiary period. (Eocene, Oligocene, Miocene, Pliocene epochs) Rise of mammals and beginnings of man.
Quaternary period. (Pleistocene epoch) Development of man. Great ice age.

Notes: 1. From the beginning of the Archeozoic era to present times represents a lapse of time of about two billion years.
2. The Archeozoic and Proterozoic eras represent about three-quarters of geologic time.

Exercises for Problem Study and Review

1. How does the rapid change in the earth's crust compare in significance with the slow change? Give examples.

2. Are "drowned" rivers advantageous to a region? Explain.

3. Compare the nebular hypothesis with the planetesimal hypothesis.

4. What is the chief difference between the planetesimal hypothesis and the tidal hypothesis?

5. How do you interpret the statement that the thousands of com-

plex substances found in the earth's crust have been made from a few simple ones?

6. Is there any danger that a shortage of free oxygen will result because it is continually being used? Explain.

7. What is erosion? Where does it occur?

8. Explain how soil is formed.

9. Justify the statement, "All sections of the United States are being damaged to some extent by uncontrolled water erosion."

10. What changes take place in a river and its valley as the river matures?

11. What is the water table? What useful purposes does it serve?

12. How do limestone caves form and then begin to fill up again?

13. Do you think that salts and other minerals found naturally in springs have greater healing power than those that are made artificially by the chemist? Explain.

14. Why do solid deposits very often form around hot springs?

15. What changes do glaciers make in areas over which they pass? Cite examples of such changes in the United States or Canada.

16. How do other agents of erosion change the landscape?

17. Explain why earthquakes and volcanoes occur in the same general regions.

18. What are fissure eruptions? Batholiths? Dikes? Sills? Laccoliths? Glacial erratics?

19. Explain the theory of isostasy.

20. How does this theory explain the location of mountain ranges along the margins of continents?

21. What facts are known about the earth's interior? How was this knowledge obtained?

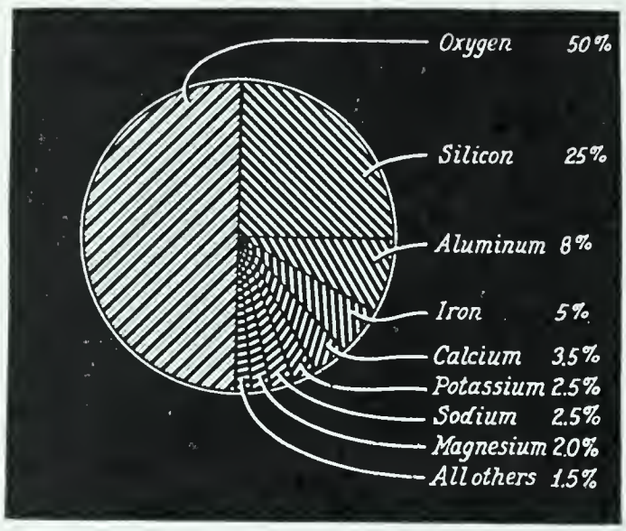
22. What scientific information about the interior of the earth should be classified as hypothesis or theory? Explain.

23. What is believed to be the most accurate estimate of the earth's age? How was it obtained?

Problem 2: What materials of the earth's crust does man obtain and use?

• ROCKS OF THE AGES

About 1,200 different minerals have been found in the earth's crust. One-eighth of these are quite common, and thirty of them are so common that they are called rock-forming minerals. A rock is usually a mixture of minerals, but occasionally it may consist of a single mineral. The name "mineral" is given to any inorganic



substance found in nature and of definite chemical composition. The minerals, in turn, are made up of chemical elements. All pure samples of any given mineral always contain the same elements in the same ratio, thus making each mineral a distinct chemical compound. Uncombined elements found in the earth also are minerals, as gold, copper, and sulfur.

The most abundant minerals are compounds of the element silicon. They are composed of silicon combined either with oxygen alone or with oxygen and other elements in compounds called *silicates*. The "other elements" may include aluminum, potassium, sodium, calcium, etc. The *feldspars* are a family of silicates which make up nearly 60 per cent of the solid crust of the earth. Mica and hornblende are other typical silicates. Sand and quartz are made up of silicon and oxygen only, except for impurities which may be present. The chemist calls the mineral they contain silicon dioxide, SiO_2, or silica. This is the most common of all the minerals.

Calcite ranks next among the minerals in abundance. It occurs in a variety of forms but is best known in the form of limestone and marble. In calcite, calcium and carbon are chemically combined with oxygen into what the chemist calls calcium carbonate, $CaCO_3$.

Although ninety-two chemical elements are known, eight of them make up the bulk of the minerals in the earth's crust. These are shown in the diagram.

Geologists recognize three main classes of rocks according to their origin. These are (1) igneous rocks, (2) sedimentary rocks, (3) metamorphic rocks. Igneous rocks are those formed by the solidification of molten material. Sedimentary rocks, as the name implies, are those which have been formed from particles which have settled out of some medium such as water and have hardened

Ewing Galloway

Ausable Chasm in the state of New York is a fine example of the down-cutting of a vigorous, young stream. Do you think the rock through which the stream is cutting is igneous, metamorphic, or sedimentary? Why?



into layers. Metamorphic rocks have been formed from igneous and sedimentary rocks which have been baked, folded, or otherwise altered by variations in the temperature and pressure of their surroundings.

The rock layers met upon digging into the earth's surface are usually made up of sedimentary rock, for such rock underlies the surface of three-fourths of the land. Continued burrowing, however, would eventually lead to igneous rock, since the sedimentary rock is only a veneer that has been deposited over the basic rock.

Igneous rocks. Granite is one of the most common rocks of igneous origin. It is made up of three minerals: feldspar, quartz, and mica. These three minerals can be recognized in a sample of granite, since the feldspar is commonly flesh-colored, the quartz light in color, and the mica dark. The texture of all igneous rock indicates something of its formation. Various samples of granite illustrate the generalization that crystals of minerals formed by rapid cooling are small, while those formed by slow cooling are large.

Granite is found scattered widely over the earth. It comprises much of our Rocky Mountains and is common along the Atlantic coast and in the interior. It is quarried and used in the construction of buildings and monuments. In general, granite is the strongest of the common building stones.

Basalt is another common igneous rock. Such rock has formed from the cooling of lava flows which succeeded in reaching the earth's surface. Since the cooling was rather rapid, basalt is very fine grained. Contrasting with these extrusions are the lava flows which failed to reach the surface. The Palisades of the Hudson River were formed by such an intrusion. The top layer of earth was eroded away at a later period. The composition of the rock formed is identical with that of basalt, but it is coarser grained. It is usually called *diabase*.

Pumice is an igneous rock sold as an abrasive. Its cellular structure was caused by bubbles of steam escaping as the molten rock solidified.

Sedimentary rocks. Gravel, sand, and clay produced by the erosion of the early rocks have been carried by wind, water, and gravity to certain areas where they have been compressed and cemented together to form new layers of sedimentary rock. Movements in the earth's crust and the weight of the upper layers have produced the necessary pressures, and water has carried in the



Courtesy G. K. Gilbert; U. S. Geological Survey

In this structure layers of limestone and shale alternate. How do you think these deposits were formed?

cementing materials. Thus *conglomerate* has formed from gravel or pebbles, *sandstone* from sand, and *shale* from clay or mud. Sandstone is widely scattered, and, next to limestone, it is the most widely used building stone.

Limestone occurs in all parts of the world in a variety of forms. All limestone is sedimentary rock and is composed principally of calcium carbonate. Various kinds of limestone differ chiefly in physical texture and in the impurities present. It is the impurities that give color to limestone. The most common kind is grayish-white, but there are blues, reds, greens, buffs, whites, and others.

This rock has been made from the shells and skeletons of certain plants and animals. From the sea water in which they lived the organisms extracted minerals which they used to form the hard parts of their bodies. The microscope reveals the individual shell patterns in some samples of limestone. Smaller quantities of limestone, it is believed, have been deposited from water by chemical action without the aid of living organisms. Natural *chalk* is really a fine-grained limestone.

More than one hundred million tons of limestone are quarried each year in the United States, and by far the greater part of it is consumed in the preparation of construction materials. Much

of it is crushed to small size for use in building roads. Certain grades of limestone are regarded highly as a building stone, especially where decorative carving is to be done; the soft limestone can easily be cut to size with diamond-tooth saws or carborundum wheels and sculptured either by hand or by air-driven tools. In addition to its extensive use as a building stone, limestone is used in large quantities in the processes of obtaining iron and other metals from their ores. It is also a raw material in the manufacture of lime, cement, and glass.

Dolomite, also a building stone, is a rock containing magnesium carbonate in addition to calcium carbonate.

Metamorphic rocks. Slate and *marble* are the commonly used metamorphic rocks. Heat and pressure have acted upon shale to produce slate and upon limestone to form marble. Vermont, Pennsylvania, and New York produce large quantities of slate. Because of its durability and the ease with which it can be split into thin sheets, it is suitable for use as blackboards and as shingles for roofing.

In a similar manner, heat and pressure have converted limestone into marble which is more compact and crystalline. This fine building stone is nearly white when pure, but it is often beautifully colored by small quantities of other minerals. Many states produce marble.

• FORMING THE MINERAL DEPOSITS

The agencies which alter the earth's surface have collected some of the minerals of the earth's crust and concentrated them in certain regions. Originally, they were thinly scattered through the earth layers. Geologists study the natural processes changing the earth so that they may know where to look for mineral deposits and how to prevent waste in the recovery of the minerals from the deposits already found.

Mineral deposits are artificially divided into the metallic and the nonmetallic groups. This is a convenient classification because the natures and origins of the two kinds of deposits are quite different.

Metallic deposits. A mineral from which a metal can be extracted profitably is called an ore. Therefore ordinary clay would not be classified as an ore, even though it contains aluminum, simply because there is no known method of extraction in which the market value of the aluminum obtained would be equal to

the cost of production. On the other hand, bauxite, which consists essentially of aluminum oxide, is an ore, for aluminum can be recovered from it profitably.

Nonmetallic minerals. By "nonmetallic," as used here to describe minerals, we do not mean that metals are necessarily absent, but that the minerals to be considered are not important ores even though they may contain some metal. A majority of the elements are metals, and there are relatively few minerals which do not contain some metal. Keep in mind the fact that any classification is made by man to suit his convenience.

The earth's ore deposits are found grouped in certain areas. These areas, as a rule, are found associated with igneous rocks. The molten earth or magma, when pouring forth during volcanic eruptions, gives off gases which solidify into compounds that are the same as those found in the ores of these metals. The production of galena, a compound of lead and sulfur, and hematite, a compound of iron and oxygen, has been observed as they formed from gases freed by the magma of Mt. Vesuvius. Galena is the chief ore of lead and much of the world's iron is obtained from hematite. This observation suggests that the magmas from which igneous rocks were formed have supplied us with deposits of metals by releasing minerals which they contained. Much of the gaseous material which is given off by the hot magma is steam which forms water as it cools and condenses. This water very often carries along in solution the ore which had condensed with it. Later, when the changes in pressure, temperature, and other factors render the ore insoluble, it is deposited in fissures or cracks in the rocks. Sometimes mineral-laden water dissolves rock through which it flows and replaces the rock with ore. Limestone is the rock most commonly replaced with ore by the action of water percolating through it.

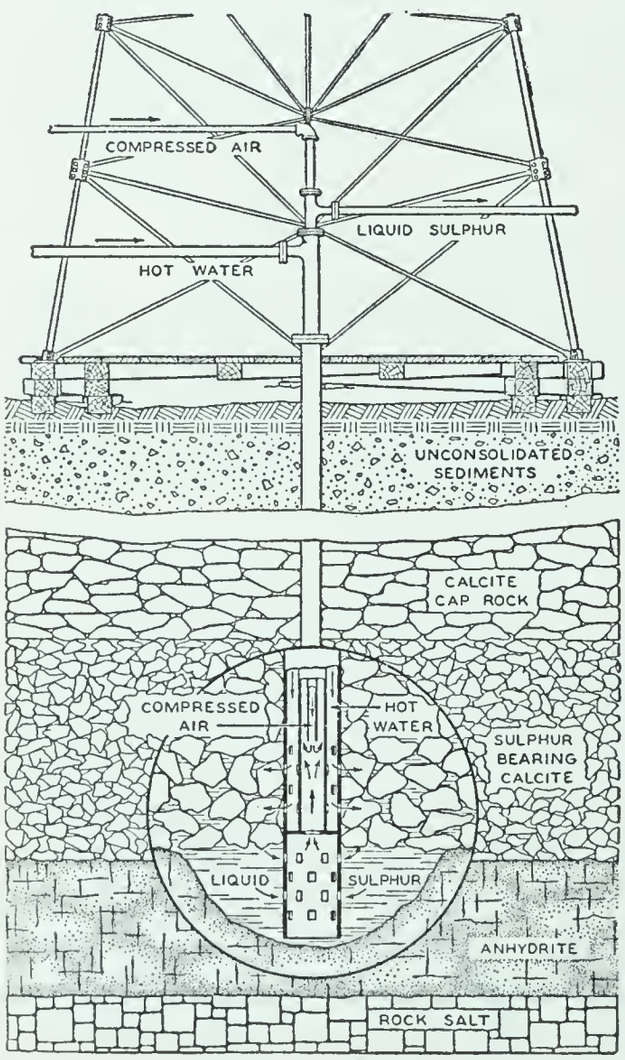
When ore is first deposited, it is likely to be a combination of the metal with sulfur, because ore-forming solutions usually carry dissolved sulfur. Oxygen and carbon dioxide from the atmosphere or substances in the earth sometimes react chemically with sulfide ores and convert them into oxides, carbonates, sulfates, or other compounds. Some metals, such as gold, will not unite readily with other substances and are therefore found free or uncombined.

In some instances the agents of erosion have been vital factors in the concentration of minerals into valuable ore deposits. The largest iron-ore deposits have been deposited as sediment rather than by igneous activity.

There is more iron ore than aluminum ore, even though aluminum makes up approximately 8 per cent of the earth's crust and iron only about 5 per cent. This is true because the minerals containing iron have been concentrated to a greater extent than those containing aluminum. There are ten known areas on the earth each of which contains more than a billion tons of iron ore. Among these are the deposits in the Lake Superior region. This deposit was originally laid down by sedimentation and was further concentrated when erosion removed the less durable earthy materials from around the iron ore. As a result, much of the ore from the Mesabi Range district contains 50 to 60 per cent of iron. Because iron is used in greater quantity than any other metal, it is often said that we are living in the Iron Age. Much of it is used in the manufacture of steel. The principal ores of iron are *hematite, limonite,* and *magnetite,* which are oxides, and *siderite,* which is a carbonate.

What properties of sulfur make possible the Frasch extraction process which is shown in the diagram below?

Courtesy Texas Gulf Sulfur Company



Copper has been known for more than two thousand years, because it occurs free as nuggets, as well as in combination with other elements. Michigan produces much ore in which copper is free, and Montana yields much in which it is chemically combined.

The only ore of aluminum used at present is *bauxite,* an oxide. Rich deposits of bauxite occur in the southern states. This oxide, when pure, is nearly one-half aluminum.

Galena, the principal ore of lead, and *zinc blende,* the main ore of zinc, are both sulfides. Lead and copper ores contain silver to such an extent that much of the world's silver is recovered from them. The United States is well supplied with the ores of these metals.

Sulfur is probably the most important nonmetallic ele-



Courtesy Texas Gulf Sulfur Company

A ton at one bite! Storage piles are seen at the left. After the blasting, the sulfur is loaded into cars and transported to various points by rail for domestic consumption; it is hauled to tidewater for export.

ment which is found as a mineral. It is found principally near active or extinct volcanoes and in other deposits where it is always associated with another mineral called *gypsum*. Gypsum, $CaSO_4(H_2O)_2$, contains sulfur, and many scientists believe that the beds of sulfur have been freed from gypsum by the action of bacteria. Enormous deposits of this type in Texas and Louisiana supply most of the world's sulfur. From the great depths where it lies, it is obtained by melting and then pumping it to the surface through pipes. The heat required to melt the sulfur comes from water which is piped to the sulfur. This water has had its temperature raised above the normal boiling point by heating it under pressure in boilers from which the steam is not allowed to escape. Compressed air also piped to the sulfur forces it to the surface.

Since nearly all chemical industries require sulfuric acid, this acid is considered to be the most important of all manufactured chemicals. Besides its use in making this acid, sulfur is needed in vulcanizing rubber and in making gunpowder, fertilizers, matches, paper, and thousands of other products.

Coal is the result of change which has taken place in accumulations of plant materials. Fragments of bark, wood, leaves, roots, and other parts of plants found in coal deposits leave no doubt as to its origin. Peat, lignite, bituminous coal, and anthracite coal represent stages in coal formation. While anthracite is commonly considered to be the limit reached in the transformation of vegetable matter by heat and pressure, some graphite is believed to have formed from such transformation carried even further.

It is interesting to imagine the conditions that must have prevailed on earth during the great coal-forming period—the Carboniferous era—which probably occurred about three hundred million years ago. It is estimated that a layer of coal seven feet thick represents an original accumulation of vegetable matter about one hundred feet deep. The slow rate at which such changes take place today indicates that the coal-forming period



Copyright Field Museum of Natural History

The coal in your bin looked like this three hundred million years ago. The scene is a restoration of a forest of the Carboniferous Era.

represents a very long period of time in the geological history of the earth. Since coal is known to be of vegetable origin, the vast accumulations of plant materials that have changed into coal indicate that vegetation must have been very luxuriant at that time. The climate must have been warm and moist, and the atmosphere must have contained a higher percentage of carbon dioxide than it does today, for these conditions favor plant growth.

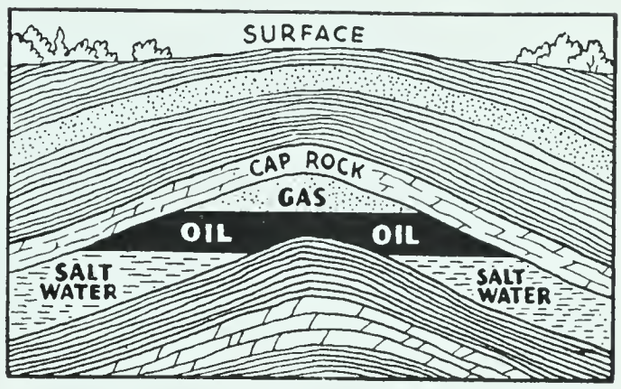
As the trees, ferns, and other plants of the time flourished and completed their life spans, their remains gradually accumulated in the swamps in deep layers. Profound geological changes were also taking place, causing the land areas to be submerged and elevated time and time again. Geologists draw this conclusion on the basis of the following evidence: (1) Coal is found in layers called veins or seams, which are separated from one another by layers of shale, sandstone, or limestone; (2) coal represents a time when the area was land, for only on this basis can the vegetation be accounted for; (3) shale, sandstone, and limestone are sedimentary rocks deposited under water and thus represent periods when the area was submerged.

Bacterial decomposition of these materials caused much of the hydrogen, oxygen, and nitrogen of which the plants were composed to escape as gases, leaving a gradually increasing residue of carbon. This residue was further modified by the pressure and heat resulting from the accumulation of sediment above and from intense folding of the rock layers. The moisture and gaseous

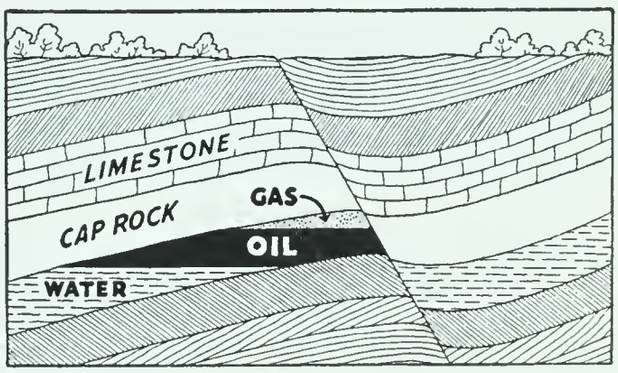
content of the coal is least where folding has produced the greatest pressure. The anthracite fields of Pennsylvania lie in the greatly folded areas of the Appalachian coal field. The great pressures due to this folding have squeezed from the coal most of its gaseous content, leaving behind chiefly solid carbon.

In this country, anthracite coal is found in large deposits in Pennsylvania only. Bituminous coal occurs in West Virginia, Pennsylvania, Ohio, and many other states.

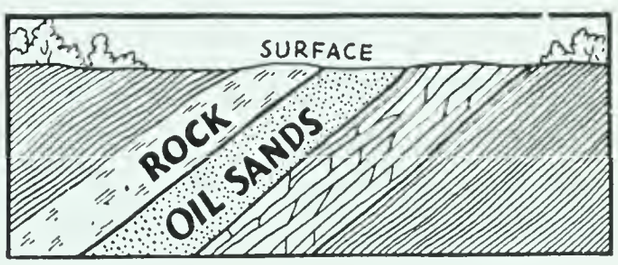
Most authorities believe that petroleum and natural gas have been derived from the decomposition of plants and animals that lived in past geological ages. It is thought that plant and animal materials decomposed and decayed under beds of mud and sand with the result that the gases and other products formed, instead of being given off into the atmosphere, were trapped and accumulated as petroleum. Another theory suggests that petroleum is a mineral product resulting from the chemical activity of the mineral constituents of certain kinds of rocks. Both theories can be supported by experimental evidence from the laboratory. However, it seems more likely that both coal and oil are of organic origin and constitute



1



2



3

Courtesy American Petroleum Institute

Man's knowledge of rocks may enable him to locate rock domes or other geological formations likely to contain oil, but only the drill can reveal its actual presence.

1. Impervious rock traps oil in subterranean reservoirs. How would you account for the relative positions of gas, oil, and water?

2. Natural rock faults, or slips, may also trap oil below the earth's surface.

3. Seepage brings oil to surface when no impervious rock prevents.

great storehouses of energy that was captured from the sun and stored up in plants and animals hundreds of millions of years ago. Both petroleum and natural gas are mixtures of hydrocarbons—that is, compounds containing only the elements hydrogen and carbon. The animals and plants which gave rise to these compounds probably lived in water, and the action of water apparently has been responsible for the concentration of these hydrocarbons between rock layers or in the porous rock itself. The hydrocarbons are found chiefly in sandstones. The compounds which are themselves liquid at ordinary temperatures and pressures, or which dissolve in the liquid compounds present, form the petroleum; while the gaseous compounds, chiefly methane, make up the natural gas. In the United States, Texas, California, and Oklahoma produce the largest quantities of petroleum, although other areas supply it in large amounts.

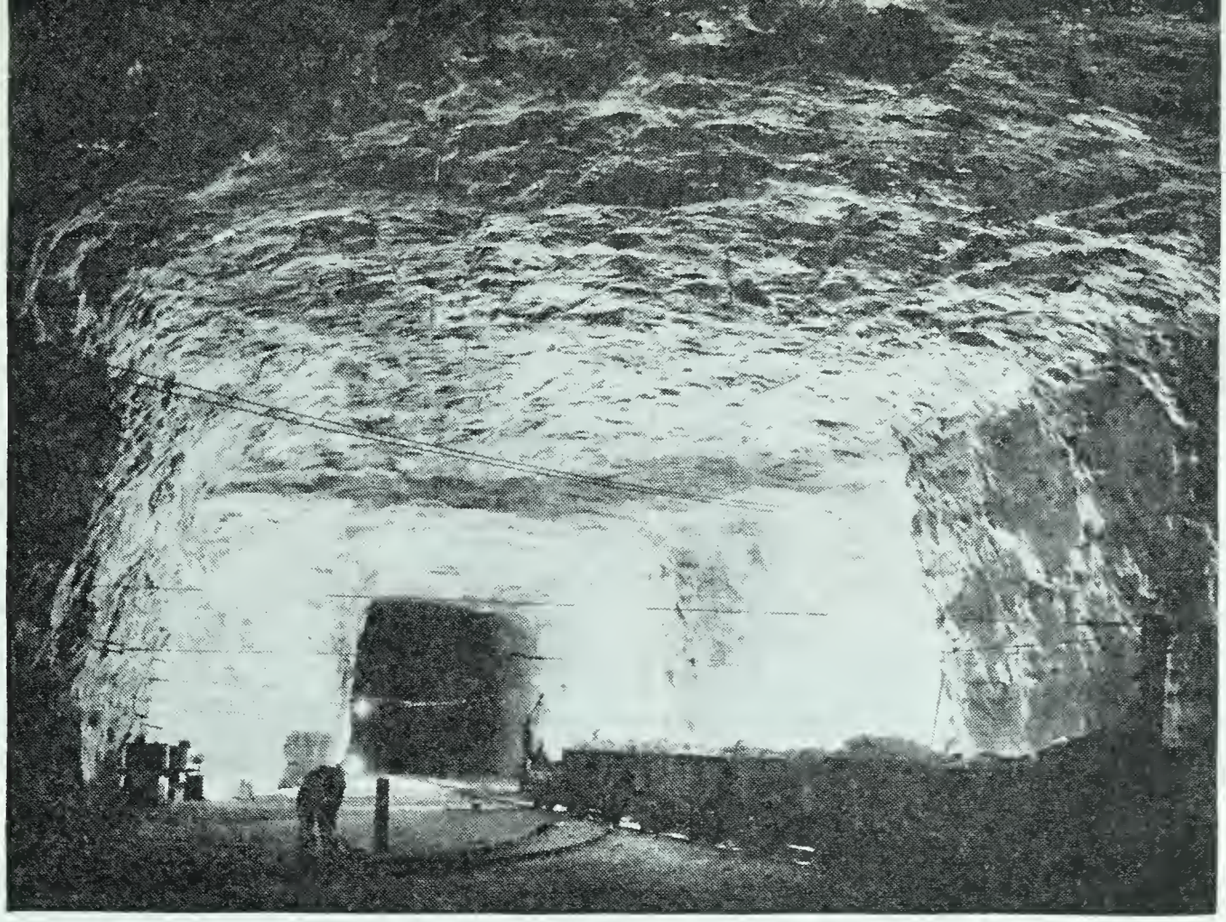
Soil is really sediment that has accumulated from the erosion of rocks. It also contains varying amounts of humus resulting from the decay of plants. The feldspars are the most common of many minerals which make up the rocks. This group of minerals accordingly ranks first in soil formation. The chemist has studied the changes in composition which a feldspar undergoes as it becomes clay, sand, and other soil particles. In his chemical shorthand he describes a typical change thus:

$$\underset{\text{(feldspar)}}{2KAlSi_3O_8} + \underset{\text{(water)}}{2H_2O} + \underset{\text{(carbon dioxide)}}{CO_2} \rightarrow \underset{\text{(form)}}{}$$

$$\underset{\text{(kaolin or clay)}}{H_4Al_2Si_2O_9} + \underset{\text{(silica or sand)}}{4SiO_2} + \underset{\text{(potassium carbonate)}}{K_2CO_3}$$

The symbols used (K for potassium, Al for aluminum, Si for silicon, O for oxygen, H for hydrogen, and C for carbon) show the chemical composition of the various substances. The chemical equation, as it is called, indicates that this feldspar when acted upon by water containing carbon dioxide gas changes into clay, sand, and potassium carbonate. Of course, the changes which produce soil are extremely slow ones.

The rock sediments are classified into gravel, sand, silt, and clay on the basis of decreasing size of particles. Most sand is composed chiefly of eroded quartz or silica with smaller amounts of silicate particles from other rocks. Gravel, likewise, usually is rich in silica. Silt and clay consist of the finest-grained products of erosion. Limestone particles are usually not present in large amounts in soil because of the dissolving action of water upon them.



Courtesy International Salt Company

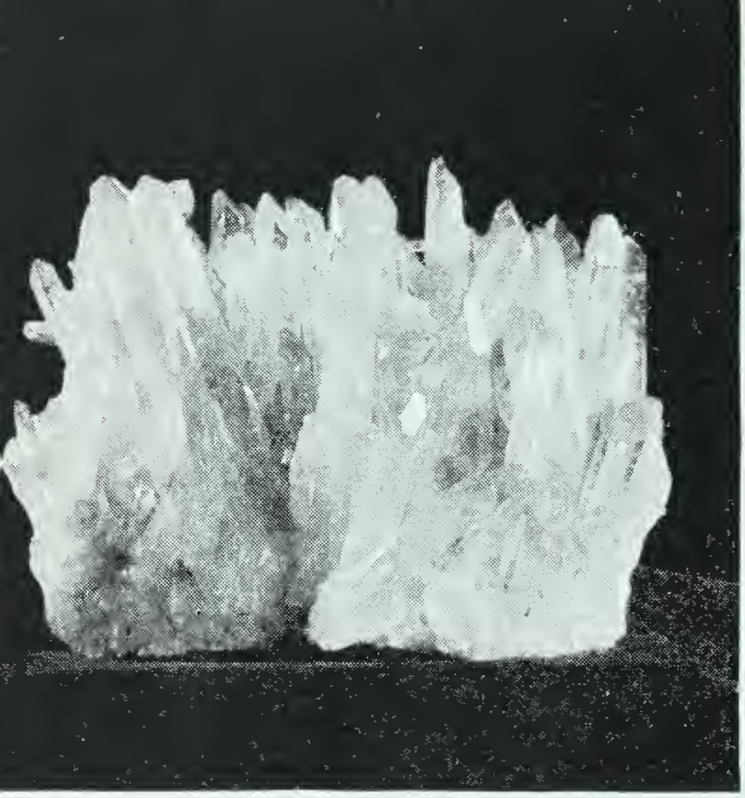
This salt mine, a man-made "mammoth cave," contains several miles of gleaming crystal corridors with roofs supported by pillars of salt.

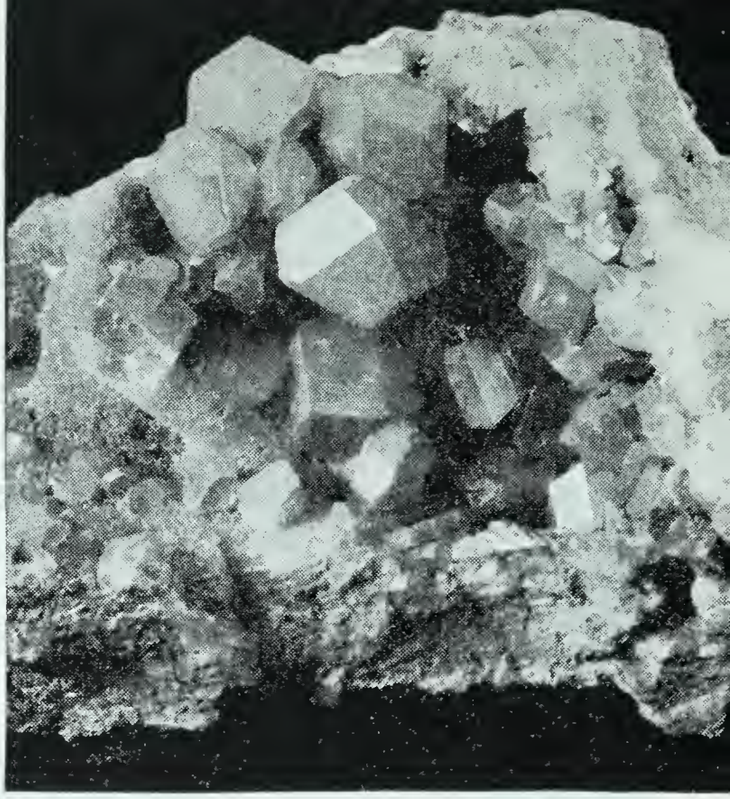
When clay is mixed with water, it becomes plastic and can be molded into objects which harden when baked. Bricks, tile, and crockery are made from it in this way. Pure white clay from the weathering of feldspar is used in the manufacture of china and porcelain. Sand is one of the constituents of concrete, plaster, mortar, and glass.

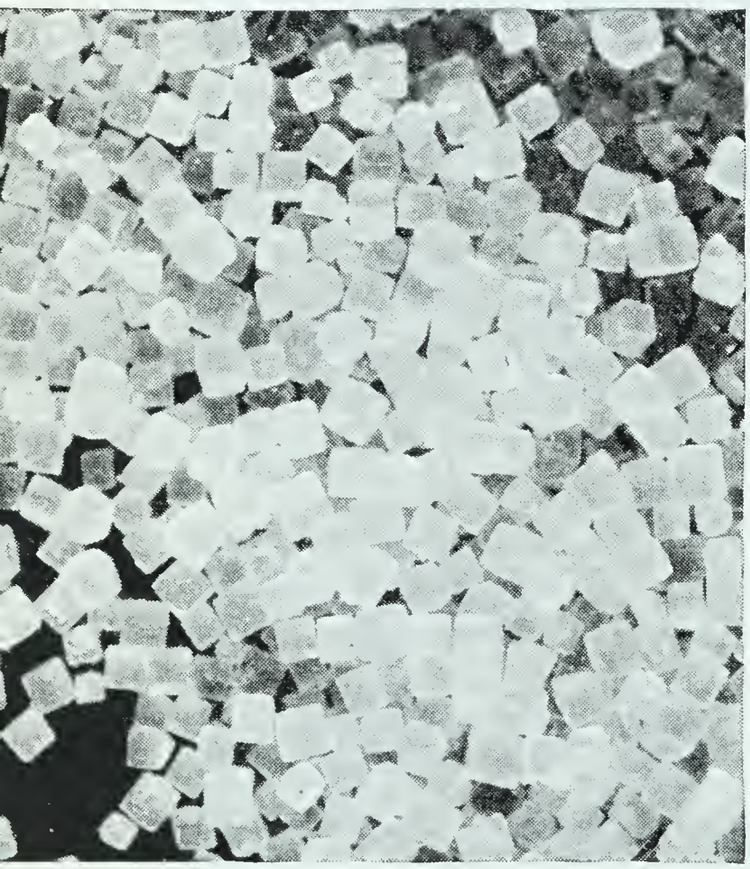
Table salt, gypsum, asbestos, mica, borax, and Chile saltpeter are other common minerals used by man. Table salt, or sodium chloride, is a good example of a mineral that has been concentrated in certain places by the dissolving action of water. About 2.5 per cent (by weight) of ocean water is made up of this salt, and salt lakes usually contain higher percentages of it. New York and Michigan have large deposits of rock salt. These beds of salt have resulted from the evaporation of former bodies of salt water. Salt is an essential article of diet and is much used in the preservation of food, in soapmaking, and in the manufacture of chemicals.

Gypsum is frequently found near deposits of rock salt. Chemically it is a form of calcium sulfate—$CaSO_4(H_2O)_2$. It is used to make plaster of Paris from which surgical casts and statues are made. Plasterboard is commonly made from gypsum.

Asbestos is a form of magnesium silicate rock mined extensively in Quebec and in smaller quantities in Arizona. It is a fibrous mineral which can be woven into thread or felted into sheets.









Photos courtesy American Museum of Natural History (top left and right, bottom right); Pepsodent Company (bottom left)

Nature builds minerals, gems, metals, and other materials of crystals. Here are four examples: quartz (top left); sulfur (top right); sodium chloride, or common table salt (bottom left); water in the form of snow (bottom right).

This fire-resistant mineral is a poor conductor of heat and electricity. Hence it is suitable for making fireproof fabrics; coverings for pipes, boilers, and furnaces; and electrical insulation.

Mica is also a silicate rock. Like asbestos, it is a good insulator for heat and electricity. It often occurs in transparent sheets which are easily split to form isinglass. Its properties make it useful as "windows" in stoves and as insulation in electrical devices. Ground mica is used in making roofing, special paints, and as "snow" in the moving-picture industry. One type of mica when heated loses some water in the form of steam. This causes it to "puff up," giving a product used in insulating buildings.

Borax is mined in the dry areas of the western states where it has been left by the evaporation of water in which it was once dissolved. Laundries use it because it is a good cleaner and water softener. Surfaces of metals are frequently cleaned with borax before soldering and welding.

Peru and Chile have large deposits of a mineral known as Chile saltpeter. Chemically, it is sodium nitrate, a combination of the elements sodium, nitrogen, and oxygen. Its importance is due to its use in fertilizers as a source of nitrogen for plants and its use in making explosives and many other chemicals.

Man utilizes some of the rarer minerals as gems because they combine beauty with other desirable qualities. The *diamond* is practically pure carbon. It has exactly the same chemical composition as graphite or lampblack, but nature has changed the carbon by heat and pressure into a crystalline form which is very beautiful. Moreover, it is the hardest substance known. Man has made artificial diamonds of microscopic size by melting carbon in cast iron and setting up great forces of contraction by suddenly cooling the mass. However, the product is chiefly graphite.

Agate and *opal* are really transparent quartz colored by small quantities of minerals. *Rubies* and *sapphires* are transparent aluminum oxide also colored by traces of other substances. *Topaz, garnet, aquamarine,* and *emerald* are other silicates containing silicon, oxygen, aluminum, and one or more other elements in chemical combination. Many of these precious stones have been made artificially after their composition has been determined. The natural gems are more highly prized than the artificial ones, even though the composition may be identical.

Studies of the nature of the rocks and recognition of folds, sedimentary layers, faults, and other structures in the earth give geologists clues as to the places where ores may have been concentrated.

In the past, prospectors using hit-and-miss methods have, of course, located valuable deposits. When the geologist unravels the story of how a certain deposit was formed, he is in a position to look for concentrations of ore in places with a similar geological history.

The contrasting properties of the various rocks and minerals have made possible the development of scientific methods of prospecting. Magnetic iron ore, for example, has been located by its deflection of the compass or dipping needle. Artificial earthquakes have been used quite successfully in locating oil. In this method, an earth-tremor caused by exploding a charge of dynamite is recorded by seismographs. The vibrations thus artificially generated travel at about four times their normal rate in the cap rock or salt dome associated with deposits of oil. Sometimes electric currents are set up between points on the earth's crust to measure the resistance of the intervening rocks. Comparison with the known resistances of ores gives helpful evidence in the search for some metal whose presence is suspected. Many ores are much better conductors of electricity than their surrounding rocks.

The scientific methods used in the search for mineral wealth give evidence of the probability rather than the certainty that the sought after deposit exists beneath the surface. Finally, holes must be drilled or sunk to confirm or disprove these probabilities. Even then there is grave danger of wrongly estimating the extent of the deposit. However, the application of scientific methods to prospecting has already proved very profitable, and further advances are to be expected.

Exercises for Problem Study and Review

1. Which are the most abundant minerals found in the earth's crust? The most common elements?
2. What are rocks? How have they been classified?
3. List several common rocks from each of the three classes and give a common use for each.
4. When is a mineral also considered an ore? Illustrate.
5. In what ways have ore deposits been concentrated in certain places?
6. Give the common name and composition of the ore for each of four common metals.
7. How is sulfur obtained from the earth? Why is it considered to be such an important element in industry?
8. In what forms is free carbon found in the earth's crust? How was each probably formed?
9. What kinds of compounds are found in petroleum and natural

gas? Give evidence to support a theory for explaining how they were formed.

10. What materials are most common in soil? What is the origin of each material?

11. List six other minerals which are used by man in large quantities and tell what these uses are.

12. Name four minerals that are used as precious stones. Why are they so highly prized? Of what are they composed?

13. What methods are employed in locating minerals? What are the advantages of scientific over unscientific methods of locating mineral deposits?

Problem 3: How does man conserve resources from the crust of the earth?

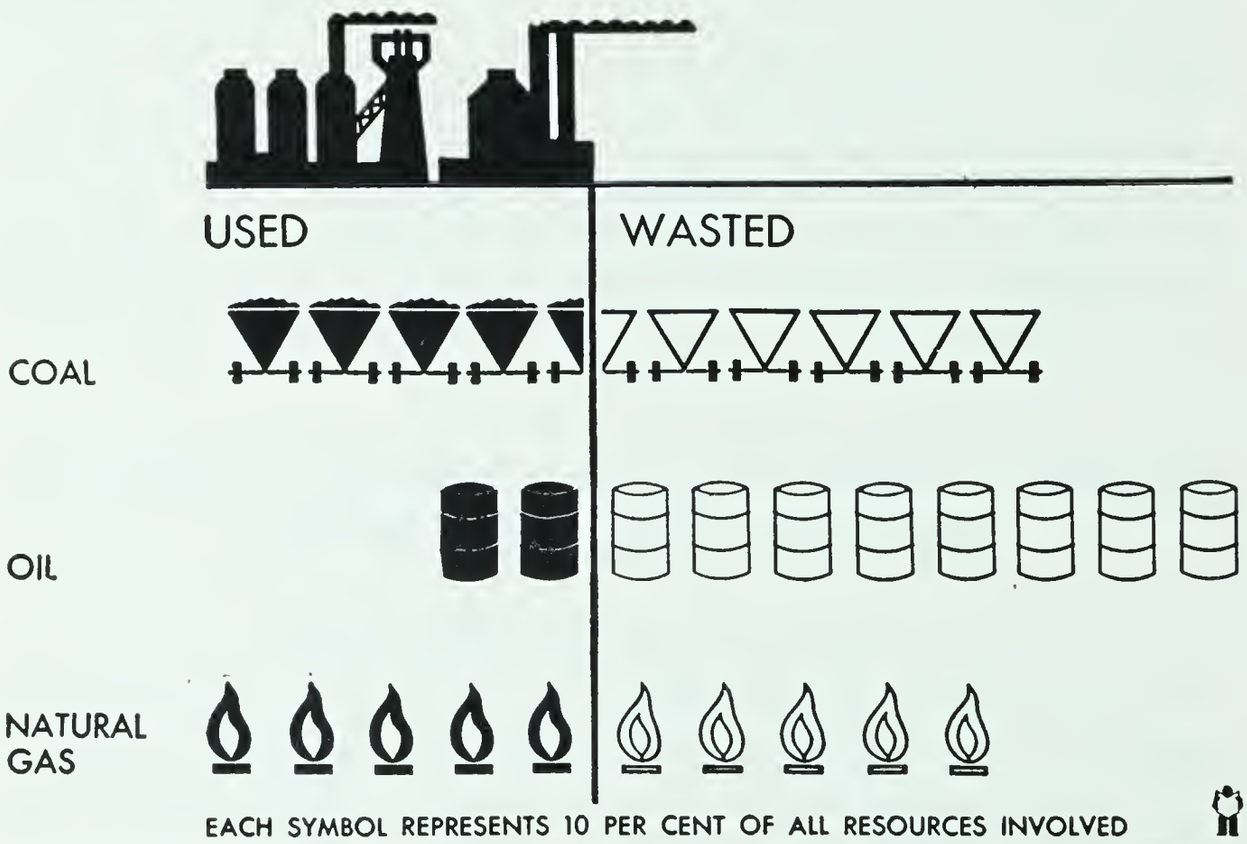
• THE NEED FOR CONSERVATION

Forward-looking citizens have long realized that man's gradual spread over the continents has been attended by needless destruction of the natural resources upon which his very existence depends. The American continent has not escaped; indeed, the destruction of its wealth has been proceeding at a very rapid rate. Even in the early settlements, a few leaders tried to slow up the exhaustion of natural resources. For example, an ordinance signed by William Penn in 1681 provided that the trees should be left on one acre in every five when land was being cleared.

In 1891, Congress enacted a law giving the President the power to set aside areas as National Forest Reserves. Not until the beginning of the present century, however, did our country really become conscious of the importance of conservation. The presidential authority has been used particularly by Theodore Roosevelt, so that we now have national forests consisting of about 140,000,000 acres in continental United States. In addition, there are other forests being preserved by the individual states. Between 1934 and 1939 the federal government carried out one of the largest land-buying programs it has ever undertaken. Nine million acres of submarginal land unsuited to farming were bought at a cost of about five dollars an acre. Under the Department of Agriculture, two-thirds of it is being put to uses for which it is best suited—national forests, grazing, recreation, and wild-life refuges. Some of it has been leased to state conservation agencies.

However, we must not make the error of thinking that these

USE AND WASTE OF RESOURCES



By Pictorial Statistics, Inc., for Bruner-Smith, *Conserving Our Natural Resources,* Merrill Publishing Company

measures have solved the problem of conservation. In fact, they do not even solve the conservation problem in regard to forests, and there are other resources beside lumber that need to be conserved. The problems of conserving water and soil are related to that of replenishing and maintaining the forests.

The extravagant use of coal and petroleum results in a loss of natural resources which can never be replaced. The North American continent, according to conservative estimates, has more than one-half of the coal reserves of the world. This is certainly fortunate for us, since coal constitutes the greatest store of available energy in the earth and is also the source material for hundreds of manufactured products. Careless methods of mining in the past have often wasted as much as three times the amount of coal that was marketed. It was common for mining concerns to remove only the coal from the larger veins where it could be obtained most cheaply. Settling or caving of mined areas makes it difficult if not impossible to get the coal thus left behind. Even in the most careful vein mining, all of the coal cannot be removed, as some must be left to support the roof.

The replacement of beehive coke ovens with by-product coke ovens has eliminated much of the waste that formerly existed when valuable gas and coal tar were allowed to escape during the manufacture of coke. The smoke nuisance and the losses due to improper combustion of coal are wastes which man knows how to eliminate but does not.

Our coal reserves will last for several thousand years at the rate at which they are being consumed. But all estimates made for petroleum indicate that the known reserves of this mineral will approach exhaustion within a comparatively few years if the present rate of consumption continues.

In 1939, Ralph J. Watkins, economic adviser to the National Resources Planning Board, reported that the economic waste in the petroleum industry, including waste capital and losses from improper production methods, might amount to one billion dollars a year. He declared, "If the actual waste is only one-half of that figure, the problem is a grave one. Even if the actual waste is only one-tenth of a billion—I do not believe anyone would place it so low—there is still a serious problem." While urging development of federal-state cooperation in conservation of oil, he stated that the nation's proved reserves and natural reservoirs then totaled seventeen billion barrels and that production during the previous year had been about one and a quarter billion barrels. His estimate of all production before 1938 was twenty-one billion barrels.

There has been great waste in the exploitation of the oil fields. Often too many wells have been sunk into the rich producing areas. Oil fields need to be developed as a unit, because many wells extend into the same underground pocket of oil. Where different companies have wells in the same area, each must continue to extract oil in order to get its share before the pocket is drained. Another great waste arises when the gas found with petroleum is allowed to escape too rapidly. Petroleum as well as fuel gas is lost, because the gas is needed to maintain pressures without which the oil cannot be brought to the surface. Gas with heating value equivalent to forty thousand tons of coal has been allowed to escape each day in the Texas Panhandle area. Oil wells have sometimes been abandoned when the output decreased, because low prices of crude oil made their operation unprofitable. One authority has estimated that for each barrel of oil that is marketed there are five barrels of oil that will never be recovered. Inefficient equipment is responsible for some of the loss.

Some of the ore deposits of the United States have already been worked out. Great Britain, Germany, Spain, and older mining countries have many abandoned mines. The great Mesabi iron range in Minnesota has passed the peak of its production insofar as high-grade ore is concerned; estimates are that the reserve of ore containing 50 per cent iron may supply the country for about one hundred years. If a way is found to use profitably ore containing only 35 per cent iron, Minnesota has enough iron ore to last for seven thousand years. Our great copper-producing centers are being rapidly depleted; gold production began to fall off in the United States over twenty years ago. In the past when one deposit was used up, another was ready to be developed. This cannot go on forever.

We must carefully decide just what we mean by conservation when discussing coal, petroleum, ores, and other resources which cannot be replaced once they have been removed from the earth. *Conservation can mean only careful use, if it is intended to bring the greatest possible good to the greatest number of people.* Very often, in the past, our resources have been exploited for the benefit of comparatively few people. The abundance of mineral wealth in the United States has led to great extravagance.

• CONSERVATION AND CONTROL OF WATER

It has often been said that we live in a "water world." All living things depend on water; it is necessary for both plant and animal life. Plants get their essential minerals from ground-water solutions. The importance of water in this particular case is clear when we realize that much arid, nonfertile soil has been rendered productive simply by irrigation. The minerals required for plant growth are present in the soil; what is needed to make them available to plants is water. In animals, the digestive system converts dry, bulky foods into soluble forms available to the cells of the body. The blood and lymph—carriers of digested foods within the body—are largely water. Water is vital also to proper cooling of the body by means of the evaporation of perspiration.

Because it travels in a cycle, there is no danger of the supply of water ever becoming exhausted. However, there is not always the right amount of water at the place where it is needed—sometimes the supply is inadequate, resulting in parched, arid regions or prolonged droughts, while at other times there is so much that it causes floods which result in loss of life and property. There is

a great deal that man can do to keep the water supply more evenly distributed.

While it is true that land covered with forests and vegetation holds back water and helps prevent floods, the effectiveness of forests as agents of flood control has probably been exaggerated. No doubt in areas now cleared, floods existed long before man removed the forests. However, they were probably somewhat less severe before the trees were removed. Today, the problem of controlling flood waters hinges about the building of structures designed for this purpose. Forests should be looked upon as supplementary aids. Forest coverings delay the melting of snow and hold back surface water during heavy rains, thereby giving it a longer time to soak into the ground. In dry periods, springs, lakes, and streams are fed by this underground water.

Effective flood control is possible. Sometimes floods can be prevented simply by cleaning and straightening the channels of the streams which overflow. In places where the banks of rivers are low, levees may be built to prevent overflow when the level of water in the stream rises. Extra space is obtained for prolonged periods of high water by building the protective dikes or levees some distance back of the banks of the stream. The strain on these devices during these times is lessened by allowing the river to flood those parts of its flood plain where it can do little or no damage. Reservoirs may be necessary to hold some of the water and protect the levees during the periods when flood stages are reached.

The Mississippi, Missouri, Illinois, Red, Arkansas, and other rivers have been equipped with levees with varying success. Levees have often failed because of improper construction. Devices constructed by one city may protect that city but cause greater damage to another city located on the same stream. Therefore it is essential that all those affected work together in attempting to keep rivers within boundaries where they cannot cause great damage.

Dams built near Dayton, Ohio, illustrate the effectiveness of retarding water in the upper reaches of streams which occasionally flood their drainage basins. Levees have also been built along the streams in this area, and river channels have been improved. Openings through the dams control the flow of water in the streams, being of such size as to allow no more water to flow from the storage basin than the channel of the stream can safely carry. Citizens of the communities protected by these dams are sure they have made a wise and lasting adjustment to the problem of preventing disastrous floods. Reservoirs properly placed throughout



Courtesy Metropolitan Water District of Southern California

This concrete-lined canal, skirting the edge of a desert hill, is a part of the system which carries Colorado River water across the state of California to thirteen cities.

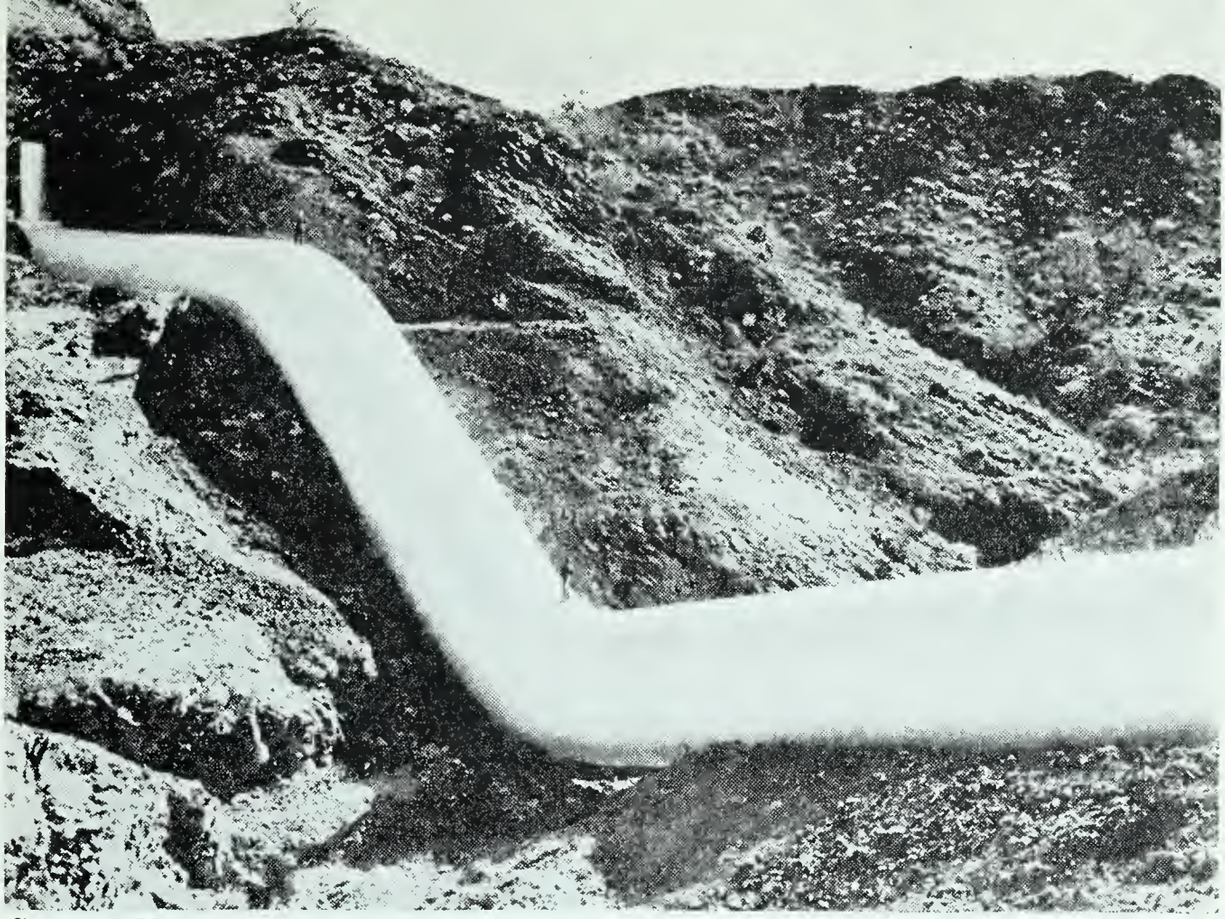
the country would bring all flood waters under control, but the cost of constructing the great number of them that would be required is prohibitive.

Sometimes, as in the Tennessee Basin, which covers territory in seven states, power development and flood control can be combined. Government funds have made possible the construction of Wilson Dam, Norris Dam, Wheeler Dam, and the other enormous dams required to regulate the flow of water in the Tennessee River and its tributaries.

Water is looked upon as the most valuable of all natural resources in regions which have been made inhabitable by irrigation. Where storage dams have been constructed in the mountains to retain water for irrigation, the danger of floods following the melting of winter snows has been lessened, and the level of the water in the streams has been held higher during dry periods. Seventeen of the western states have arid or semiarid regions, and approximately nineteen million acres are being irrigated. Authorities estimate that enough water could be made available to irrigate an additional twenty million acres. The Bureau of Reclamation of the federal government and private interests have directed and supported irrigation projects.

What is your share of the water supplied daily to your community? In the largest cities, the average consumption each day for each person is approximately 150 gallons. Smaller communities average somewhat less. Ancient Rome, with its fountains and baths, used twice as much water daily per capita as the average of our largest cities.

Centers of population, for the most part, have developed in areas



Courtesy Metropolitan Water District of Southern California

Another part of the system shown in the picture on page 382 is this giant inverted siphon on the main line of the aqueduct. The size of this big reinforced concrete structure, which is sixteen feet in diameter, may be noted by comparing it with the size of the two men standing on it.

where there is normally an adequate supply of water. Springs, ordinary wells, artesian wells, rivers, and lakes are the sources from which communities usually get their supply of water. Cities located near large rivers or the Great Lakes have unfailing supplies. However, even a large river may prove unable to supply its own basin with water for homes, irrigation projects, and industries and also to furnish unrestricted amounts to the distant cities which tap it. Los Angeles originally obtained all of its water from the Los Angeles River, but, as the city expanded, it had to turn for more water first to the Owens River 238 miles away and then, recently, to the Colorado River nearly four hundred miles away.

To bring the Colorado River water to southern California, Parker Dam, with a foundation one-eighth of a mile deep—the deepest in the world, was built 155 miles downstream from Boulder Dam. Then 108 miles of tunnels had to be drilled through rock, dry soil, and water-bearing sand, and concrete linings were constructed. Sixty-three miles of open canals were dug and lined with concrete, and many miles of concrete-covered conduits were built. The intake pumping plant lifts the water over mountains and empties it into the Metropolitan Aqueduct, starting it on a 392-mile journey to thirteen southern California cities.

If the Woolworth Building were placed on top of the R.C.A.

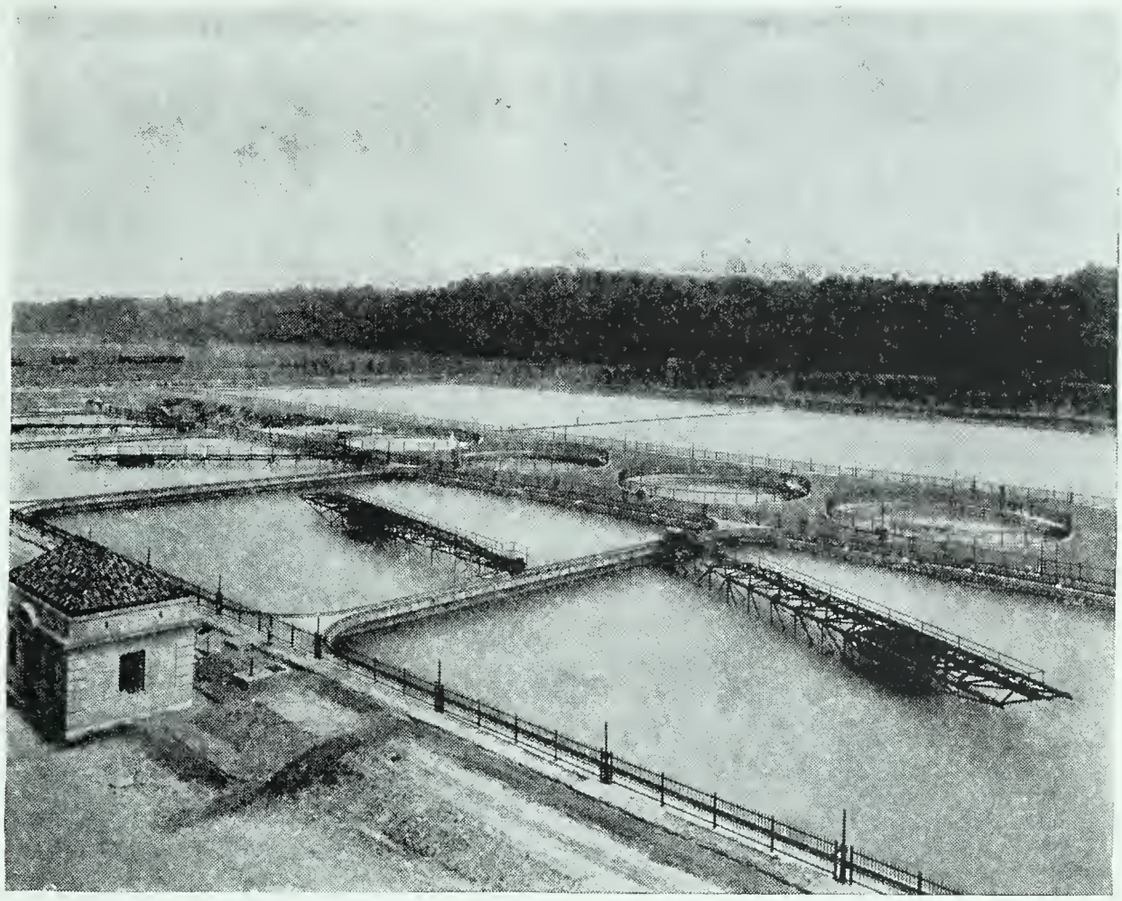
Building at Rockefeller Center, and if a young river were continuously pumped to the top of this structure and allowed to flow by gravity down to Youngstown, Ohio, there to be treated and distributed to surrounding cities, one would have an approximate idea of what happens to the Colorado River when it travels to Los Angeles. The power for pumping would provide illumination for a city as large as Detroit.

Connecticut and Massachusetts have had legal battles over the diversion of water from the tributaries of the Connecticut River; New Jersey and New York have fought similarly over the Delaware. New York City has had to look for new sources of water periodically. Its latest project, tapping the headwaters of the Delaware River, will solve the problem, it is estimated, for at least several decades after its completion.

Thus water is evidently one of the factors which determines whether or not communities can continue to grow. It is not mere chance that Nevada, which is on the average the driest of the states, also has the least dense population. Reno, within this state, Salt Lake City in Utah, and other similar communities depend for water upon mountain streams partly fed by the melting of snow on the mountains.

Water is no doubt a much wasted commodity. It is ordinarily so plentiful and cheap that we use several times the required amount for nearly every purpose. The average quantity of water used is considerably less in communities where it is metered and sold by the gallon than in areas where a fixed charge is made yearly. Large communities are sometimes threatened by water shortage during periods of little rainfall. During such times, wasting water becomes inexcusable and communities often pass ordinances to provide penalties for extravagance. In such emergencies we realize more fully that water is one of our most important natural resources and that, although the supply will never become exhausted, there are certain limitations on the supply which must be recognized.

The extent to which water is ordinarily wasted and the manner in which the public will respond to intelligent conservation education was demonstrated in New York City during the late months of 1939 and the early months of 1940. A prolonged dry spell had caused the water level in the reservoirs to fall until they were little more than one-third full, and the situation was becoming serious. The public was appealed to by way of newspapers, radio, television, and newsreel programs and by the distribution of two mil-

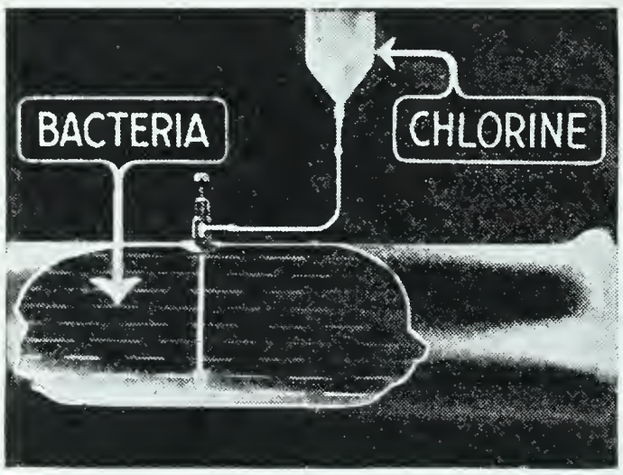


Courtesy National Lime Association

Mixing tanks and settling basins are used in the purification of water. Calcium hydroxide and aluminum sulfate react with each other to form a precipitate. As the precipitate settles to the bottom, it carries with it suspended impurities in the water.

lion "Conserve your water supply" pamphlets. Thousands of "Stop that leak" posters were displayed in restaurants, cafeterias, real-estate firms, gasoline stations and garages, banks, laundries, theaters, and other public places. One hotel alone reported that it saved 60,000 gallons of water a day by checking all leaky fixtures and by asking its guests to cooperate with it in the city's campaign. Another hotel cut the amount of water used by 15 per cent. In the city as a whole, the average daily consumption dropped 25,000,000 gallons during December, 1939, as compared with the same month of the previous year. The saving rose to 29,400,000 gallons per day during the following month by the same method of comparison and became even greater before rains again filled the depleted reservoirs.

Formerly the problem of purifying water to prevent the spread of disease was a more serious one than it is today. Sewage, plant and animal wastes, and drainage from other sources provide food for the growth of bacteria. Milwaukee, Chicago, Buffalo, and



Courtesy Eastman Kodak Company

The fatal effect of chlorine on bacteria safeguards man against their harmful, and possibly fatal, effect.

many other communities not only take water from the Great Lakes but also dump sewage into them. Cities frequently make similar use of rivers. In fact, few localities have supplies of water pure enough for human consumption without preliminary treatment. The effectiveness of such treatment is shown by the great decrease during recent years in deaths from typhoid fever and other diseases caused by bacteria spread by water. Inoculation also has been an important factor.

The purification of water to make it safe for domestic use consists of removing the suspended particles and killing the bacteria present. If the amount of suspended material is great, the water is first allowed to stand in tanks where much of the solid matter settles out; the cleared water is run through sand filters. The addition of two chemicals, aluminum sulfate and lime, coagulates the fine particles and speeds up the settling process. In the rapid mechanical sand filter, which is the type commonly used by municipalities, the water is passed through the filter under pressure to speed up the filtering process. The particles of solid matter and much of the bacterial content are removed. A gelatinous film on the sand grains, formed by adding aluminum sulfate and lime, helps coagulate and retain the solid impurities.

Chlorine is added to the filtered water to kill the remaining bacteria. This poisonous element, when present to the extent of about two pounds per million gallons of water, is harmless to humans and large animals but fatal to bacteria. It could be used in even greater concentration without making the water supply unfit for use. The more progressive communities also treat sewage with chlorine before dumping it into rivers and lakes. Some European cities use ozone, a form of oxygen, as a water disinfectant. Boiling for a sufficient length of time also kills bacteria, but the cost of the fuel required makes the boiling of large quantities of water impractical. In small amounts, water can be made safe for drinking purposes by treating it with chlorinated lime, a chemical product that can be purchased in nearly any drug, hardware, or grocery store. Directions for use are printed on the labels of the

containers. Boy Scouts, campers, hikers, and tourists often insure the safety of questionable water by the use of chlorinated lime tablets, which can be purchased at drug stores. About ten drops of ordinary tincture of iodine in each gallon of water will also insure its safety as far as bacteria are concerned. It should stand twenty minutes before using.

• SAVING THE SOIL

Having recognized soil erosion as a menace to the national welfare, the United States government created in 1933 an agency called the Soil Erosion Service. Two years later, Congress changed the name to the Soil Conservation Service and declared it to be "the policy of Congress to provide permanently for the control and prevention of soil erosion and thereby to preserve natural resources."

Private groups have also recognized the importance of the fight against soil erosion. An example is the nonprofit, nonpartisan association, "Friends of the Land," which held its first meeting in March, 1940, at Washington, D. C. Sponsors and supporters of the association included many prominent persons, among them being Stuart Chase, Charles A. Beard, and Dr. Albert Einstein. The organizing chairman, Morris L. Cooke, outlined the problem thus:

"Soil misuse makes people poor. Soil displacement is followed by human displacement. The first shock of displacement is felt in the open country. But soon, as yields and trade fall off, it is also felt in the towns. Our land is all of one body. We, as a people, are all of one body. We all live on or from the soil.

"No matter which political party gains ascendancy, as the years go by, whether we remain at peace or go to war again, this fact will remain: so long as we keep scrubbing off top soil and wounding our water resources, business and social conditions in the country will remain fundamentally unsound.

"Within the government and without, we need conservation programs which recognize the essential unity of soil, water, forest, game, and human problems and which are so coordinated as to advance as one. Whether our principal interest be in soil, water, songbirds, game, or forests; whether we are thinking in immediate terms of soil to be restored, floods to be quieted, or in the ultimate terms of human security, we can all work together for the good of the country.

"In launching this effort we are moved by the feeling that informed citizens, working outside the government can do much



Tennessee Valley Authority

Uncontrolled running water has slashed these deep gullies in the face of this hill. At the extreme right, check dams, brush matting, and other types of erosion-control work may be seen.

that needs to be done to make conservation programs pull more closely together, deliver more for the dollar, and make sense.

"We have talked a great deal about conservation in this country lately. We have barely begun to do something about it in a large, sensible, and connected way. The need to do more is urgent. The record is plain. Over vast areas we stand confronted with defaced landscapes, depleted water supplies, and an all but catastrophic degradation of soil and man."

Man is responsible for the unnatural erosion which he is now trying to bring under control. It began as soon as the pioneers began to clear the land. When the land surface still had its natural cover of vegetation, the agents of erosion did not remove soil any faster than they rebuilt it. After this cover was removed, destructive erosion speeded up until its rate soon surpassed that of soil formation. The government agencies report that many areas have already been so badly eroded that they are practically incurable. Other areas, though severely afflicted, can be saved, but the recovery will be a slow one. Preventing further unnatural erosion and checking it where it has just begun are more fruitful than curative treatment, because hundreds of years are needed for the replacement of a single inch of topsoil by natural forces. Thus the problem is chiefly one of preserving the "good earth" that remains.

The experimental work that has been done thus far indicates that erosion can be arrested and the restoration of eroded land begun. A number of measures have proved effective. The simplest

measure is to return a natural cover of vegetation to land that erodes badly. Steep slopes are the worst victims because they fall prey to surface water moving swiftly after heavy rain. Trees in very steep areas and grass for pasture in less steep ones are recommended. Close-growing crops such as hay, timothy, clover, alfalfa, and soybeans form a cover which allows little loss of soil.

Contour farming is another effective measure. Rectangular fields with crops in straight rows are a source of pride to the farmer, but the slope of the land may make another arrangement desirable. "Square" farming on rolling lands is a common cause of damage by erosion. An experiment carried out in New Jersey by the Soil Conservation Service showed that there was only one-nineteenth as much soil lost when corn was planted across sloping land as when it was planted in rows running up and down. Contour farming thus consists of planting in rows curving across and at right angles to the slope of land which is not level. *Strip farming* is a form of contour farming in which strips or bands of crops, such as corn or potatoes, which are not close growing, are alternated with strips of close-growing crops, such as hay, clover, or alfalfa.

When the above measures are not effective in controlling erosion, they may be aided by certain mechanical measures. The formation of gullies by water which collects in the depressions is one of the most serious threats to farm land. The gullies widen and deepen with each successive rainfall. If some way can be found to check temporarily the water at the gully head, a cover of hardy, quick-growing vegetation can be established. Sometimes dams built of loose stone, wood, brush, or sod must be used as temporary measures for halting the growth of a gully. The slowed-up water deposits sediment and helps fill the eroded area.

Terraces are really shallow channels hollowed out to catch water running down the surfaces of a slope. They curve around contours at right angles to the slope. This holding back of water gives longer time for its absorption by the soil. Down channels connect the terraces and carry off the excess water. These up-and-down waterways must be constructed with stone, cement, or other materials which do not erode easily.

The United States Department of Agriculture through its Soil Conservation Service issues separate bulletins for the various sections of the country in which it makes specific recommendations for erosion control. One such bulletin, for example, is entitled "Conserving the Corn Belt Soil." These pamphlets can be obtained

at very little cost from the Superintendent of Documents, Washington, D. C.

• KEEPING SOIL FERTILE

Soils which are suitable for the growth of crops are termed fertile soils. The fertility of soil decreases as crops are grown in it and as water seeps through it. What the soil gradually loses is its content of water-soluble minerals. These pass with water through the root hairs of plants and become part of the plant body, or they are carried away by surface water and underground streams. In time, there is a decided drop in crop yield from land which is cultivated year after year without replenishing certain minerals.

Carbon, hydrogen, and oxygen are the elements which make up most of the plant body, but smaller quantities of nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, and other chemical elements are also essential to plant growth. When chemical changes in the soil do not replenish the supply of available minerals rapidly enough to keep pace with the removal of such minerals, soils become exhausted—like overdrawn bank accounts. Man must then feed the soil. Fortunately, only three elements need to be considered for this purpose, since practically all of the other ten or twelve elements required are present in all soils in amounts sufficient for essential needs. The three elements referred to are nitrogen, potassium, and phosphorus. None of these elements is furnished to the plant as a free element but rather as part of some compound. Water itself furnishes hydrogen and oxygen. The problem of maintaining soil fertility, then, is solved by returning to the land proper amounts of nitrogen, potassium, and phosphorus in the form of compounds which are soluble in water.

Materials which supply the elements in which soils are deficient are called fertilizers. A *mixed,* or *complete,* fertilizer supplies the "big three"—nitrogen, phosphorus, and potassium—in suitable amounts. Animal manures, ground bone, and other animal or plant products have long been used as fertilizers because they contain soluble compounds of the needed elements. Artificial fertilizers made by mixing chemical compounds of these elements are, however, of first importance.

As a protection to consumers, most states have laws which regulate the manufacture and sale of commercial fertilizers. These laws require the manufacturer to label his product correctly, giv-

ing the per cent of nitrogen, phosphorus, and potassium present, and to guarantee the amount of available plant food contained therein.

There are practically no nitrogen-containing minerals in the soil. Most of the nitrogen that plants use comes from the air by chemical processes called *nitrogen fixation* or from various nitrogenous fertilizers. Important fertilizers are various natural manures, green manures (plowed-under crops), dried blood, meat meal, hoof meal, fish scrap, sodium nitrate, ammonium sulfate, and other chemicals.

A few plants enrich the soil in which they grow by adding nitrogen compounds. Peas, beans, clover, and alfalfa are well-known plants which perform this function. They are called *legumes* by the biologist. If you carefully uproot one of these plants so as not to lose the delicate parts of the root system, you will find small knobs or nodules clinging to the roots. These nodules contain bacteria which are able to take nitrogen from the atmosphere and manufacture from it nitrogen compounds which the legume can use. Ordinary plants cannot make use of atmospheric nitrogen as these bacteria can. Excess nitrogen compounds which the growing plant does not need are left in the ground. This is the reason why a legume is usually included when farmers systematically rotate crops to conserve the fertility of their fields.

Large beds of sodium nitrate occur in Chile and Peru. This compound is extensively exported for use in the manufacture of fertilizers and explosives. It is called Chile saltpeter. About 1913, chemical processes were developed for manufacturing nitrogen compounds by causing nitrogen from the atmosphere to unite chemically with other substances. Today, these chemicals are competing successfully in the fertilizer industry with sodium nitrate from South America.

Most soils contain very small percentages of phosphorus, some as low as .01 per cent. Consequently, the farmer must purchase appreciable amounts of phosphorus fertilizer to replenish that which has been removed by growing crops. Grains, in particular, need large amounts of phosphorus. Phosphorus fertilizers are made chiefly from the ground bones of animals, blast-furnace slag, and mineral-phosphate deposits. Stable-manures also provide phosphorus.

Large deposits of phosphate rock are found in our southern states and in Wyoming. As such, it is of no use to plants, because it will not dissolve in water. However, when the rock is treated

with sulfuric acid, a soluble compound of phosphorus is formed. This *superphosphate,* as the new material is called, is widely used in fertilizers.

The Tennessee Valley Authority has experimented with the production of plant food from the phosphate rock found in central Tennessee. The result is a new material called *triple phosphate.* Through the cooperation of local soil-conservation associations with the Authority, the farmers of the region have been instructed in the use of this fertilizer, particularly in raising close-growing crops which are effective in the control of soil erosion.

Until recently practically all of the potassium compounds used in fertilizers came from the Stassfurt mines. Vast deposits of potassium salts were discovered at Stassfurt, Prussia, in 1681, and for many years they were the world's principal source of this vital element. During the last twenty-five years, considerable quantities of potassium salts have been extracted from the brines of certain lakes of western United States, particularly from Searles Lake, California. Still more recently, large deposits of a mixture of sodium and potassium chlorides have been found in New Mexico near the famous Carlsbad Caverns. The salts occur under a large area in a layer ten to twelve feet thick. The mines of New Mexico are now able to produce each year much more potassium than is used in the United States. As a result, Germany no longer has the monopoly on potassium which she held for many years, and the United States is independent of foreign sources of this essential material.

Some soils seem to be "sick." They contain all the components of a rich soil—sand, clay, and humus—and have adequate amounts of essential chemical elements; yet they will not grow crops. Investigation of such soils has shown them to be deficient in soil bacteria. It is known that several different kinds of bacteria are present in a fertile soil, and a nonfertile soil can often be rendered productive by simply "sowing" it with the kinds of necessary bacteria which are missing.

Soils in continuous use tend to become "sour." This condition results from the accumulation of acids in the soil—acids which are produced by bacterial decay of plant materials and humus. Excess acids retard the growth of some crops, and certain varieties of soil bacteria do not thrive in an acid condition. Some soils contain enough limestone to neutralize these acids, but those that are lacking in this mineral must be treated from time to time with pulverized limestone. Many soils in our southern states are deficient

in limestone and must be treated to bring them over to "the alkaline side."

Exercises for Problem Study and Review

1. In what ways have we been wasteful with our reserves of lumber? Coal? Oil? Gas? Metals?
2. What is the outlook for the future with respect to coal? Iron? Petroleum?
3. Why does an oil field need to be developed as a unit?
4. What is meant by conservation?
5. How does the supply of water on the earth compare with what was here centuries ago? Explain.
6. What various measures have been taken to prevent floods?
7. Give evidence to support the statement, "Water is one of the factors which determine whether or not communities can continue to grow."
8. Has intelligent conservation education proved effective in the past? Explain.
9. How is water made safe for domestic use on a large scale? How can it be done on a small scale?
10. How in the past has man proved to be an enemy of the soil which supports him?
11. Describe several methods that have proved effective in saving the soil.
12. What factors decrease soil fertility?
13. What is a complete fertilizer? Why do most states require detailed labeling of fertilizers?
14. What is nitrogen fixation? Why is it so important?
15. How do legumes enrich soil in which they grow?
16. What are the sources of materials used to enrich soils in phosphorus? In potassium?
17. Soils are not always fertile even though they are not lacking in essential elements. In what other ways might they be defective? How can each defect be overcome?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. When does a frozen water pipe burst—when the water freezes or when the ice melts? Explain.
2. If a flask partly filled with water and containing a cork stopper is heated until the water boils, the stopper blows out, and much of the water is thrown explosively from the flask. Explain this action and compare it to a natural phenomenon.
3. How do you explain the fact that when snow falls on a busy

street or highway, it soon becomes a layer of ice, while elsewhere it remains as snow?

4. A suburban district of a certain Midwestern city is called Moraine Park. What kind of topography would you expect to find there?

5. The formation in New Hampshire known as the Great Stone Face or the Old Man of the Mountain faces almost due south. What is the probable explanation for its formation?

6. Will the forces of erosion ever reduce the earth to a smooth sphere? Why?

7. What might the surface of the earth be like if it had no atmosphere?

8. What evidence indicates that climates in various parts of the earth have changed?

9. How would you account for the great deposits of limestone in our central states and for the layers of stratified rock high among mountainous regions?

10. Do you think coal beds are now being formed? Soil? Explain.

11. If the mountainous parts of the earth are continually being worn down, why are mountains still in existence?

12. If you were conducting an automobile tour through your state and wished to point out five interesting geological formations, which ones would you select? What explanation would you give for each?

UNIT WORD LIST

earth's crust
nebular hypothesis
planetesimal hypothesis
tidal hypothesis
erosion
soil
water table
stalactite
stalagmite
geyser
glacier
moraine
seismograph
theory of isostasy
element
mineral
ore
igneous
metamorphic
sedimentary
symbol
contour farming
strip farming
terraces
fertile soil
fertilizer
nitrogen fixation
legumes
alkaline

INTERESTING THINGS TO DO

1. Prepare a collection of rocks and minerals from your locality.
2. Prepare a collection of as many ores of metals as you can obtain.

3. Prepare a collection of pamphlets relating to soil conservation and make them available for class use. Get them from your state department of agriculture and from the Superintendent of Documents, Washington, D. C.

4. Visit a limestone cavern and describe it to the class.

5. Visit a marble or granite quarry.

6. Take a trip down into a coal mine.

7. Make a collection of photographs showing examples of erosion in your locality.

8. Make a list of several of the outstanding scenic regions of the United States and give a brief geological explanation for the formation of each.

9. Make a chart to scale (1 inch equals 1,000 feet, for example), on which show (1) the greatest ocean depth; (2) the highest elevation in your state; (3) the highest elevation in the United States; (4) the highest elevation in North America; (5) the highest elevation in the world.

10. Make a table of three columns. List the following in the first column: waterfall, irregular shoreline, block mountains, lacustrine plain, geyser, canyon, water gap, cinder cone, lava cone. In the second column give a brief explanation of the cause or method of formation of each, and in the third column give one example of each.

11. Imagine that a huge clock was started at the beginning of the Archeozoic era and that every tick represents the passing of one thousand years. Calculate how many hours, minutes, and seconds have elapsed (1) since the clock was started; (2) during the Archeozoic era; (3) during the Proterozoic era; (4) during the Paleozoic era; (5) during the Mesozoic era; (6) since the beginning of the Cenozoic era; (7) since primitive man appeared; (8) since man dominated the earth and civilization began; (9) since recorded history began; (10) since the Declaration of Independence was signed.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Glacial history of North America.
2. Erosion and flood-control services of the United States government.
3. Destructive earthquakes and their effects.
4. Famous volcanic eruptions and their effects.
5. Geological history of Niagara Falls.
6. Artificial or synthetic man-made gems.
7. The natural resources of my state.
8. Methods of estimating the age of the earth.
9. Geological history of mountains of the United States.
10. Prehistoric men and their fossil remains.
11. The story of the Grand Canyon.
12. Methods of locating mineral deposits in the earth.

13. Famous geologists and their work.
14. The story of the "Land o' Lakes."

INTERESTING BOOKS TO READ

Chase, Stuart, *Rich Land, Poor Land.* McGraw-Hill Book Company, New York, 1936. Calls attention to the waste of natural resources in America. Interesting illustrations.

Croneis, Carey G., and Krumbein, William C., *Down to Earth: An Introduction to Geology.* The University of Chicago Press, Chicago, 1936. The illustrations alone would make this an interesting and instructive reference.

Fitzhugh, Edward F., Jr., *Treasures in the Earth.* The Caxton Printers, Limited, Caldwell, Idaho, 1936. The story of how metals are first concentrated and then deposited in veins or other types of ore bodies.

Fletcher, Gustav L., *Earth Science, a Physiography.* D. C. Heath and Company, Boston, 1938. An elementary textbook useful in learning about the crust of the earth, the sky, and weather and climate. Contains many excellent illustrations and exercises.

Furnas, Clifford C., *The Storehouse of Civilization.* Bureau of Publications, Teachers College, Columbia University, New York, 1939. A discussion of the social and economic aspects of problems of producing, using, and conserving natural raw materials. Interesting charts and graphs included.

Johnson, Gaylord, *The Story of Earthquakes and Volcanoes.* Julian Messner, Incorporated, New York, 1938. One of the most complete treatises on earthquakes and volcanoes; also one of the most simple and most understandable.

Pickwell, Gayle, *Deserts.* McGraw-Hill Book Company, New York, 1939. A fascinating story of deserts and desert life. Sixty-three beautiful photographs make this an outstanding book.

Pryor, William C. and Helen S., *Water—Wealth or Waste.* Harcourt, Brace and Company, New York, 1939. A book which treats the problem of water conservation in a practical, realistic way. The photographic illustrations, themselves, vividly portray the drama of water.

Reed, W. Maxwell, *America's Treasure.* Harcourt, Brace and Company, New York, 1939. Interesting, though somewhat rambling, discussion of treasures in the earth in the United States. Numerous well-chosen illustrations.

Sears, Paul B., *Deserts on the March.* University of Oklahoma Press, Norman, Oklahoma, 1935. A discussion of the work of weather and its control.

Verrill, A. Hyatt, *Minerals, Metals and Gems.* L. C. Page and Company, Boston, 1939. An enjoyable book which gives interesting history, curious characteristics, and other fascinating facts about minerals, metals, and stones. The style is simple and nontechnical.

ESSEMER PROCESS IS IN FAVOR AGAIN

vival Brought About by the earmament Program and Output Is Stepped Up

The revival of the Bessemer ocess of making steel under the pulsion of the national defense gram bids fair to become one the main achievements of the el industry in these times of un-cedented demand. In recent rs the output of the open hearth naces has been actively pushed the steel companies for various ctical reasons, but the Bessemer duct was permitted to fall into favor. Now the industry is at-pting to rehabilitate the mar- for Bessemer steels.

S. Indicts 5 Platinum Plot

ew York, Dec. 3.—(UP)—Five n, including two former stew-s on Pan American Clippers e indicted today on charges of spiracy to smuggle platinum out

EW MATERIALS TO BEAUTIFY HOME

lletin Announces Creation f Glass Block Containing Rich Color Effects

MBWAITER SIMPLIFIED

oduct for Storefront Is evised to Minimize Plate Glass Breakage

ANY USES ARE FOUND OR LUMBER IN HOMES

lder Explains Availability of Different Varieties

Pig Iron Scarcity Grows as Threat To Steel Output

Lack Felt in East; Scrap Reported Sold $15 Above 'Ceiling'

Old Paper Drive Aids Defense

Old magazines and newspapers

UNIT SIX MATERIALS FOR CONSTRUCTION

Plastic Toys Have Become More Popular

Tin Output Drops Sharply in October

SIGNS INDICATE TERMITE ACTIIVTY

Destructive Pests Often Give Evidences of Presence Around the Home

PROMPT INSPECTION VITAL

Owner Advised to Consult Expert When Evidences of Damage Appear

RAPS SMELTERS FOR WASTE OF RARE METALS

Claims Millions of Pounds Go Up Chimney by Care-less Processes

U.S.-Argentina in Tungsten Deal

Synthetic Fiber to Rival Silk Offered in Coal-Basis Process

Versatility Claimed for Textile Made From Vinyl Resin—New Diabetes Insulin Patented

U. S. Navy Planning Aluminum Destroyers

Plastic Pickup May Follow War

St. Louis, Dec. 4.—(AP)—Uncle Sam may get a plastic pickup for his



Unit Six

MATERIALS FOR CONSTRUCTION

Steam shovels belched and groaned as they dug out tons of earth and rock. Trucks loaded to capacity worked their way from the yawning hole up plank ramps to the street surface. Tons of concrete gushed through long chutes into shafts dug down hundreds of feet to bedrock. Girders swung into place like pieces of a jigsaw puzzle as riveters and welders joined them securely into a strong rigid framework. Another skyscraper was climbing—slowly but surely—to take its place among the spires of the city's canyons.

Building a skyscraper is only one of hundreds of construction jobs that go on every day. Things are always being built: buildings of all types, roadways, automobiles, radios, fountain pens, rubber tires, refrigerators, clothing, machinery, etc. For all these products, countless construction materials are needed, and through the work of scientists, such needs have been satisfied.

A big difference between the past and today is our increased knowledge and control of the forces and materials of nature. The same raw materials that we use today—wood, stone, sand, clay, metallic ores, plant materials, etc.—surrounded early peoples, but they used them in very primitive fashion, if at all. An increased knowledge of chemistry, the development of larger amounts of power, and the invention of machinery have all contributed to improved standards of living by making the resources of the earth available for all sorts of construction.

Man has always been faced with the problem of *obtaining* raw materials for construction; he has found it desirable and even necessary to alter or *adapt* them for use. In the *use* of construction materials, man must consider the forces of wind, of water, of gravity, and of earthquakes and the twists, pulls, and thrusts, if his buildings and other structures are to be safe, strong, and sound. Man has waged a constant battle with nature to retain possession of his construction materials: metals rust and corrode; wood rots and decays or is attacked by termites; fabrics stain and become soiled. Among man's greatest and costliest problems is that of *caring for* and *preserving* construction materials. These are the major adjustment problems relating to construction materials.

Courtesy U. S. Steel Corporation; photo by Robert Yarnall Richie

Problem 1: How do we use minerals in the manufacture of nonmetallic building materials?

• LIMESTONE AND GYPSUM PRODUCTS

We learned in the last unit that an enormous tonnage of limestone is used directly in construction work of various kinds. In addition, very large quantities serve as the starting point in the preparation of several vital building materials which are produced by means of chemical action. Among these materials are lime and slaked lime.

Lime is also known as quicklime and burnt lime. It is such a useful material that two million tons or more are produced annually in this country. The method of preparing lime consists of heating crushed limestone or waste marble chips in either a vertical or rotary kiln. The intense heat causes the calcium carbonate to decompose, giving off carbon dioxide and yielding calcium oxide, which is the lime:

$$\underset{\text{calcium carbonate}}{\underset{CaCO_3}{\text{limestone}}} \xrightarrow{\text{heated}} \underset{\text{calcium oxide}}{\underset{CaO}{\text{lime}}} + \underset{CO_2}{\text{carbon dioxide}}$$

Lime is used in glassmaking and in the extraction of metals from their ores, but perhaps its most important application is in making *slaked lime.* This is done simply by adding water, either at the factory or at the time of use:

$$\underset{\text{calcium oxide}}{\underset{CaO}{\text{lime}}} + \underset{H_2O}{\text{water}} \rightarrow \underset{\text{calcium hydroxide}}{\underset{Ca(OH)_2}{\text{slaked lime}}}$$

The slaking of lime liberates a great deal of heat; hence it should be done cautiously. When masons make slaked lime "on the job," they generally let it slake for at least forty-eight hours before using it.

Some idea of the importance of slaked lime can be gained by noting that, besides its extensive chemical applications, it is used in water softening, in removing the hair from hides to be made into leather, and in mortar and plaster.

Calcium sulfate is one of the abundant minerals found in the earth's crust. It occurs in several varieties, two of the useful

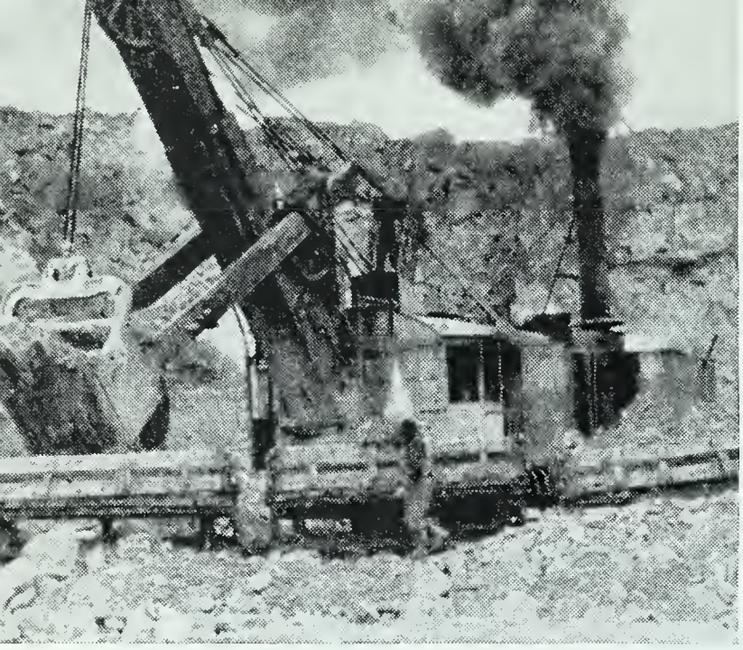
ones being *gypsum* and *alabaster*. Alabaster is found in a variety of colors—white, pink, buff, and others—and is soft and durable. For these reasons, it is a favorite material for use in making statuary, small articles such as lamp bases, book ends, candlesticks, and vases, and other decorative carvings. It is too soft to be used as a building stone.

Gypsum is mined chiefly in New York, Michigan, Iowa, Texas, and Ohio, although at least twenty states contribute to the total annual production of about three million tons. It is chiefly used in the manufacture of paints, as a filler for certain grades of paper, and as the source material for the manufacture of plaster of Paris.

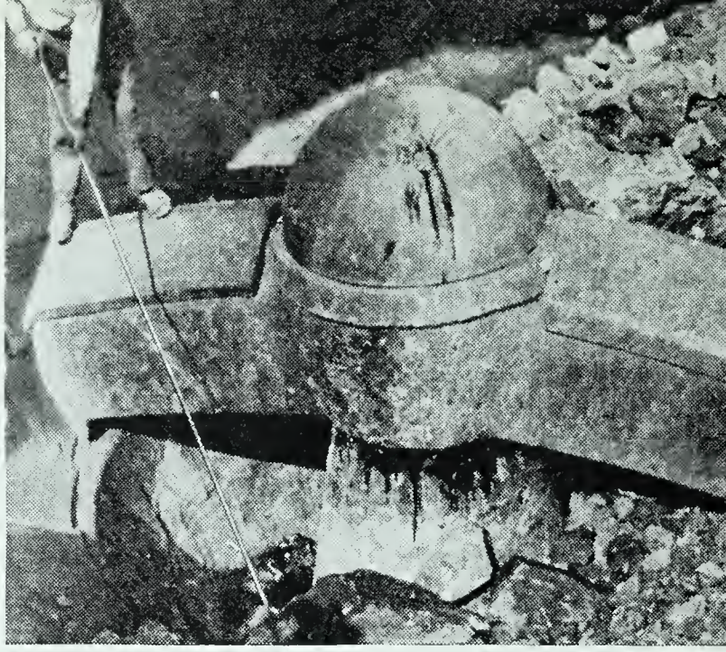
When gypsum is properly heated, moisture is expelled, and the resulting product when pulverized to a fine powder is plaster of Paris. It is used for making plaster casts in surgery and art work, in the manufacture of wall board or plasterboard, and in making the white finish coat in plastering. Chemical industries produce large amounts of calcium sulfate as a by-product, and some manufacturers are now utilizing this instead of natural gypsum for making fireproof and insulating boards for flooring, roofing, and siding.

Broadly defined, cement is a material which, upon being mixed with water to form a paste, acquires the property of setting and will harden under water. Joseph Aspdin, a mason of Leeds, England, was granted the first patent on Portland cement in 1824. He heated a mixture of natural chalk and clay. When the resulting product was powdered, mixed with water, and allowed to harden, it formed a stonelike mass resembling Portland rock, a famous building stone of England; hence the name, Portland cement. Practically all cement manufactured today is Portland cement.

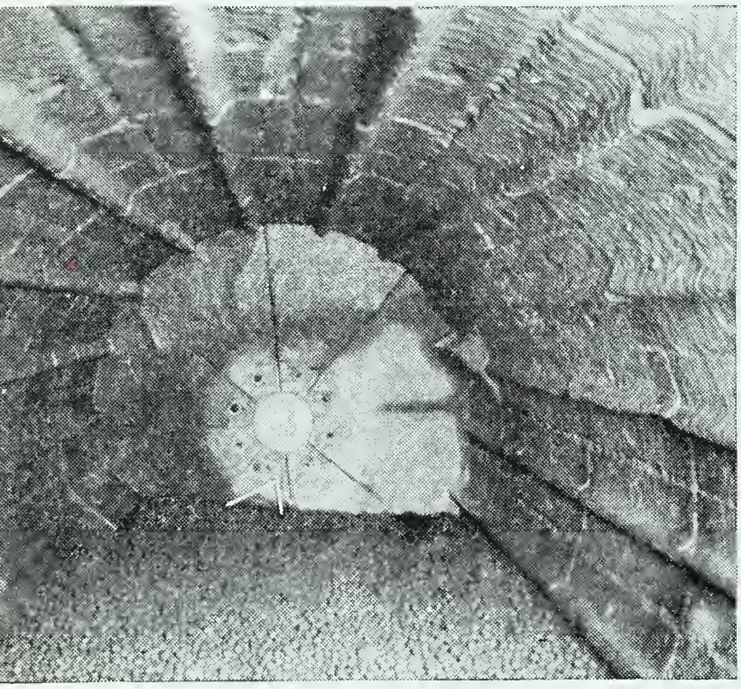
Making cement can be compared to baking a loaf of bread. The baker sifts the flour and mixes all the ingredients in correct amounts. The cementmaker quarries his raw materials—limestone and shale or clay—and grinds them to a fine powder, which he also mixes in definite amounts. The baker puts the dough into an oven and bakes it for perhaps an hour at a temperature of 400° Fahrenheit, which converts it into bread. The cementmaker feeds the mixture of raw materials into a huge, inclined rotary kiln and "bakes" it for perhaps eight hours at a temperature of about 2700° Fahrenheit. The intense heat is obtained by using powdered coal as fuel, although oil or gas can be used. The fuel is blown in and causes a long tongue of flame to shoot far into the kiln. However, the cementmaker is not yet finished. When "baked" in the kiln, the raw mixture fuses and forms what is known as *clinker*. After



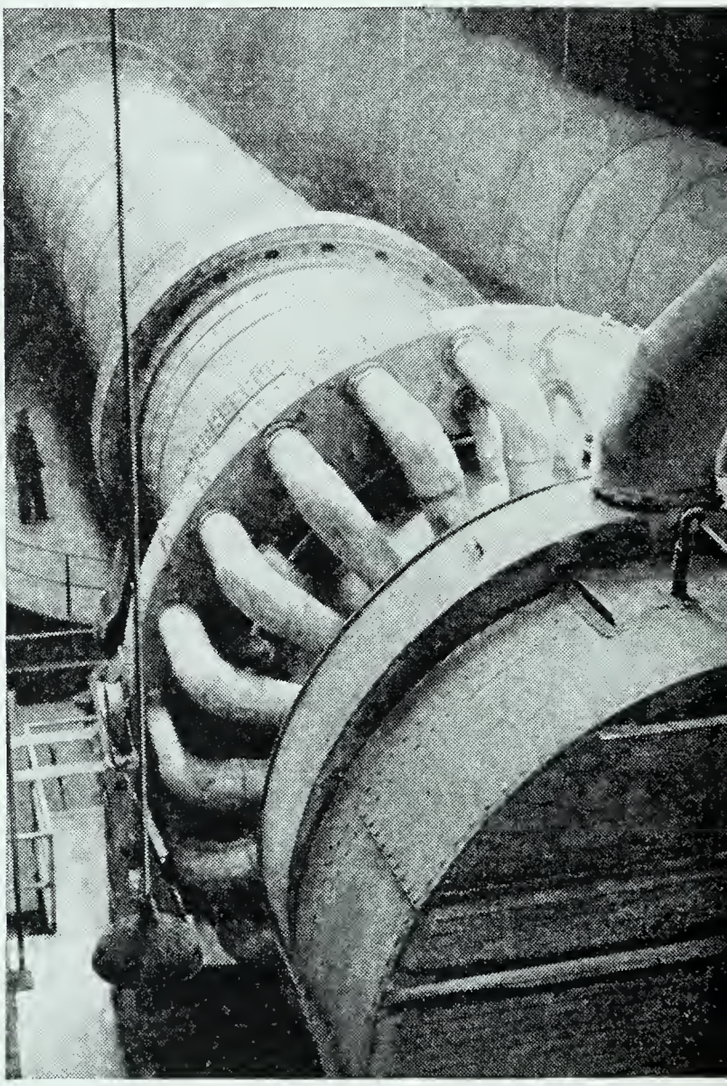
A power shovel loads broken rock to be used in making cement into cars which carry it to . . .



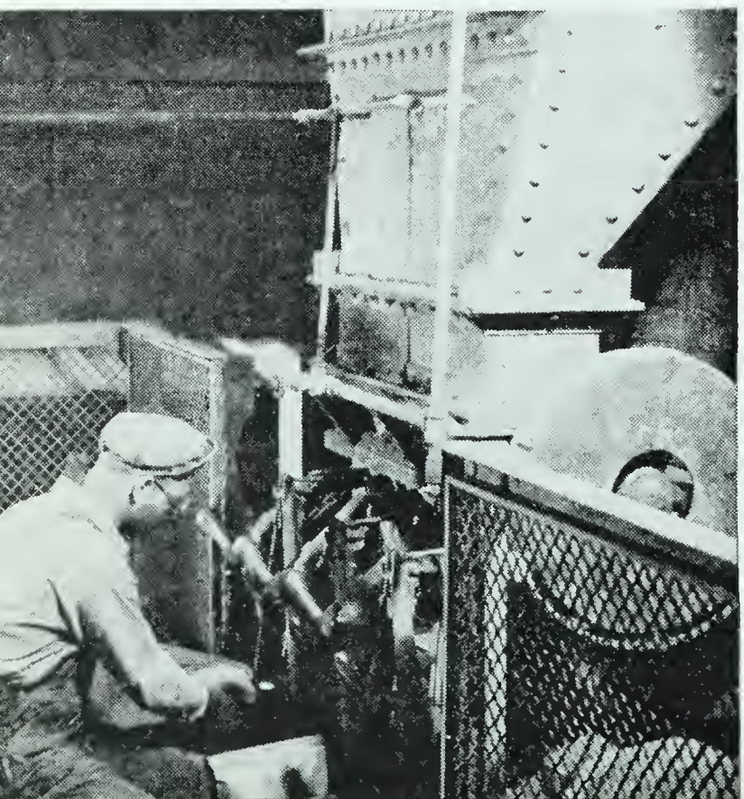
. . . the gigantic crusher. Clay and shale or blast-furnace slag are added, and the mixture is powdered in . . .



. . . rotating-ball mills lined with armor plate and partly filled with steel balls.



"Burning" occurs in a rotary cement kiln (above). An average-sized kiln is longer than a twenty-story building is high. The fuel is powdered coal, fuel gas, or oil.



Marble-sized, glass-hard balls called clinkers slowly emerge from the rotating inclined kiln (left) and are ground into a powder and packed in sacks.

Photographs courtesy Portland Cement Association

the clinker leaves the lower end of the kiln, it is cooled and ground to a very fine powder which is cement. The finished cement is put into sacks or barrels. In over thirty states in this country there are more than 150 cement plants, producing about 150,000,000 barrels of cement annually.

When cement is used to make concrete, it is mixed with water and usually sand or gravel, very often both. The cement and water in the mixture combine to form a paste or glue, which surrounds the particles of sand and gravel and upon hardening binds the entire mass together. The strength of the concrete depends directly upon the strength of the paste; hence it is highly important to use the right ratio of water to cement when mixing. The amount of water actually needed by the cement in hardening is small in comparison with the amount needed to give the mixture a working consistency. If too much water is used, the paste becomes thin and watery, and its strength is reduced. In general, the less water used the greater the final strength of the concrete. The American Concrete Institute recommends the use of from 5¼ to 8¼ gallons of water per sack of cement and that just enough sand and coarser material be mixed with this paste to produce a concrete that will work readily into the corners and angles of the forms without excessive tamping and without allowing free water to collect on the surface.

Concrete sets rather quickly, but it continues to harden and gain strength over a period of many days. The chemical reactions that occur during the hardening process take place very slowly. Water is necessary for these reactions, and if the water evaporates during the early days of setting, the resulting concrete will be weaker than if the full amount of water were present. To prevent the absorption of water from the concrete mixture, wooden forms should be cleaned of all chips and shavings and be thoroughly wet or oiled just before use. It is also necessary to keep concrete properly moist for about ten days after it is laid. It is common practice in construction work to sprinkle fresh concrete with water occasionally or to cover it with moist burlap, straw, sand, or earth. In the construction of concrete highways, contractors often coat the surface of the fresh concrete with a tarlike preparation which prevents evaporation of water. The setting of concrete liberates heat, which in huge construction jobs creates quite a problem. In the construction of Boulder Dam, large pipes were built into the structure to carry cold water for absorbing the heat.

Because of its strength, durability, and the ease with which it

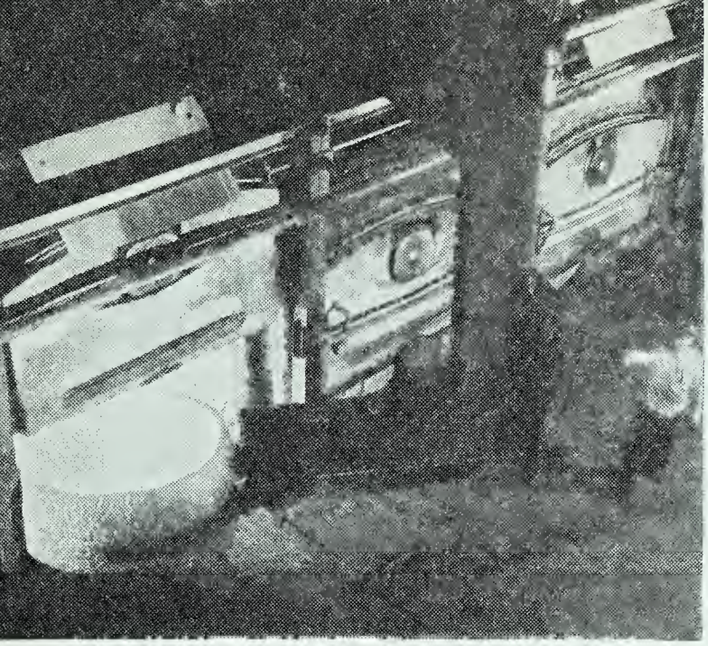
can be worked, concrete is used in the construction of roadways, sidewalks, bridges, buildings, monuments, and in numerous other ways.

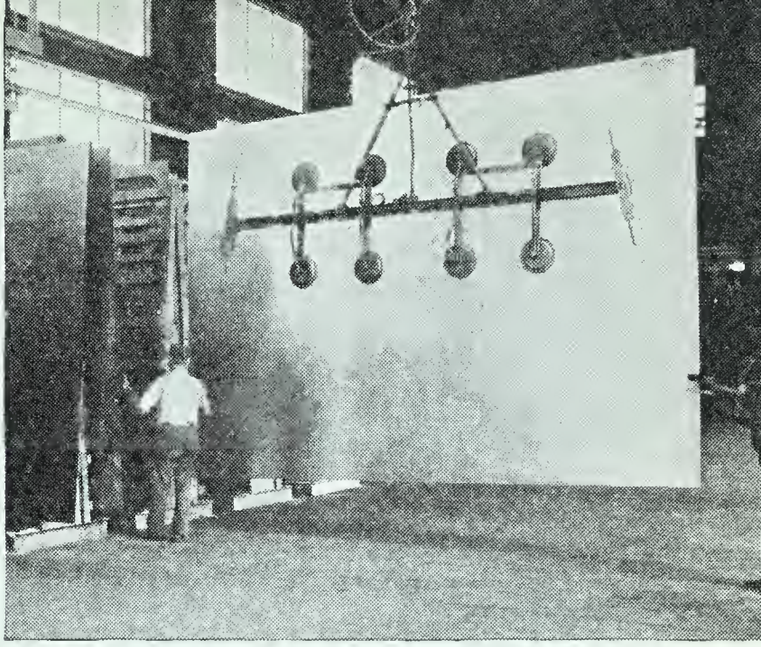
There are several kinds of mortars and plasters used for many types of construction work. The ingredients most often employed in preparing these mixtures are slaked lime, Portland cement, plaster of Paris or other gypsum products, sand, hair from the hides of cattle, and water. At present nearly all brick and tile masonry and stucco work is done with *Portland cement mortar,* which is made of cement, slaked lime, sand, and enough water to make it workable. It is affected very little by water and is highly fire resistant.

In recent years, *gypsum plasters* or *hard wall plasters* have come into widespread use. The base of these products is very similar to plaster of Paris, being prepared by heating gypsum rock to specified temperatures to expel moisture, but they contain, in addition, some material such as clay which controls the time of setting. Many of these plasters can be obtained with all their ingredients—gypsum plaster, lime, sand, and hair—properly mixed at the factory and ready for use upon the addition of water. The *finish coat* on white plastered walls is generally made of slaked lime and plaster of Paris, or *Keene's cement*—a high-grade plaster made by heating carefully selected gypsum rock and treating the resulting product with alum. Keene's cement gives a hard, dense coat of great strength; it is much used for decorative plastering work and for sanitary purposes where there is exposure to moisture.

The setting and hardening of mortars and plasters result chiefly from chemical action—not simply from "drying out." In discussing Portland cement, this action has already been described. It is the same with plaster of Paris; its chemical union with water causes the same substance to form that was present in the original rocklike gypsum. In the case of slaked lime, setting is due to the evaporation of water, but hardening continues for many years and results from chemical union of the lime with atmospheric carbon dioxide to form calcium carbonate, which, you will recall, is the chief chemical substance in limestone and marble:

slaked lime calcium hydroxide		carbon dioxide		calcium carbonate		water
$Ca(OH)_2$	+	CO_2	→	$CaCO_3$	+	H_2O





Courtesy Libbey-Owens-Ford Glass Company

Left: A giant steel claw is withdrawing a pot containing nearly 3,000 pounds of molten glass. This process is likely to be used for special orders, whereas the continuous flat-drawing process is used for window glass and other types of glass made regularly.
Right: A vacuum-cup crane is seen lifting a "blank" of unpolished plate glass from the annealing ovens. It next goes to the grinding and polishing lines.

• SAND AND CLAY PRODUCTS

Recorded history is not old enough to tell us when the art of making glass began. There are some evidences, however, including passages in the Bible, to indicate that glasslike materials were made and used in Egypt at least five thousand years ago. One story credits the discovery of glass to shipwrecked Phoenician sailors, who used lumps of their sodium nitrate cargo instead of stones to build a fireplace and support for their kettles. Afterwards they were amazed to find that the wood ashes, sand, and nitrate under the intense heat of their fire had melted together and formed glass.

Glass has become an indispensable material of modern civilization. It has been one of the chief aids to man in making adjustments to the world around him. Without glass for lenses, mirrors, and prisms, the nature of the solar system and the world of very small organisms such as bacteria would still be a mystery. The lens of the camera has extended the range of man's vision and has enabled him to illustrate with photographs the records of historical events and ideas. We preserve our eyesight with glass spectacles. In our homes, window glass gives us light and nearly invisible protection against driving winds and beating rains. We use glass for tableware and decorative effects. Our food is preserved in glass containers. Glass promises to become a still more important building material, now that glass bricks for construction purposes and spun-glass wool for insulation are being made and used. This enumeration of the uses of glass is by no means complete; it merely



Courtesy Libbey-Owens-Ford Glass Co.

A corner of the "sandwich shop" where a sheet of plastic is placed between two layers of plate glass to make safety glass. The combination is then subjected to terrific hydraulic pressure in steel tubs of hot liquid. The plastic becomes very transparent, and the "sandwich" merges into what appears to be one pane of glass.

suggests the importance of glass and why it is worth while to know how modern varieties of glass are made.

The raw materials used in making glass consist essentially of selected sand, lime or limestone, and sodium carbonate. After preliminary cleaning processes, these materials are carefully weighed and mixed, pressed into briquettes, and fed into a furnace usually fired by gas and air. The temperature within causes the charge to melt and react chemically, forming a sticky, molten mass, which can be cast, rolled, blown, or drawn into the desired shape or form. Formerly all glass objects were made by glass blowers, but modern machinery is now available for use in making window glass, glass bottles, and other kinds of glass products. *Window glass* is usually "flat drawn"—that is, an iron bar is lowered into the furnace, and, as it is withdrawn, molten glass sticks to it and is drawn out into a continuous ribbon. The glass must be cooled very carefully lest it become solidified and rigid on the surface before it does so in the interior. Improper cooling causes glass to be brittle and to shatter when scratched or shocked even slightly. The cooling is often done in "lehrs"—long, low tunnel-like ovens arranged so that a high temperature can be maintained at the receiving end, gradually decreasing to atmospheric temperature at the other end. The glassware is carried through the lehrs on slow-moving, endless conveyors, emerging properly annealed—that is, properly subjected to the heating and cooling process.

As a general rule, *plate glass* is made of the same carefully selected materials as ordinary window glass. The batch is melted in a large pot and, when ready, is poured upon a perfectly flat, cast-iron table where it is flattened by a heavy roller—much as pie

dough is flattened by a rolling pin. After proper annealing, the rough sheet is ground to a true plane, polished, and cut to size for use.

Safety glass is really a glass sandwich. Two pieces of smooth, polished glass cut to size and shape are coated on one surface with a transparent cementing material, and a sheet of a suitable transparent plastic is inserted between them. They are pressed together and heated under pressure. The edges are then ground and polished and sealed with a waterproofing material.

Different kinds of glass with desired properties for special uses are made by slight alterations in composition. *Optical glass* contains compounds of lead, which make it clear and brilliant. The inclusion of borax in glass gives a product capable of withstanding high temperatures and rather severe temperature changes without cracking; *Pyrex* brand glass is an example. Colors in glass are produced by adding chemical compounds of various metals—gold, copper, or selenium for red, cobalt for blue, chromium or iron for green, and others for different colors.

Quartz, the most abundant mineral in the earth's crust, is found in a variety of forms ranging from rock crystal to sand. Pure sand is composed almost wholly of quartz grains. Upon being heated to a temperature of about 1700° centigrade, quartz melts and looks very much like molten glass, which it also resembles in that it can be molded or cast. Quartz resists the action of most chemicals and withstands severe temperature changes without cracking. These properties make it useful in manufacturing thermometers, lenses, and laboratory apparatus. *Quartz glass* is used in windows where it is desired to get the healthful ultraviolet rays of sunlight, as in hospitals and sanitariums; ordinary glass does not admit these rays.

Clay is formed from decomposed, weathered rock, and a variety of products are manufactured from the many grades of clay available. High-grade clays are used to make chinaware, porcelain, terra cotta, and fine pottery, while low grades of clay are used in making brick and tile. It is the character of the clay or clay mix that influences the appearance of the product. The purer the clay, the whiter the appearance. Various impurities, chiefly metallic oxides, produce the wide range of color found, especially in brick; ordinary brick, for example, is colored red by iron oxide similar to iron rust.

The essential ideas underlying the manufacture of such products have changed but little from antiquity; however, increased chemical knowledge of clays and modern machinery enable man to pro-

duce better-quality products on a much larger scale and at a lower price. In general, all of these products are made by carefully weighing and mixing the raw materials, molding the raw mixture to size and shape, drying, and "burning" at a suitable temperature.

If it is desired to *glaze* brick, tile, or pottery, the burning process is carried on at a higher than usual temperature, thus causing some of the surface clay to melt and form a natural glaze. Salt-glazed brick and tile are made by throwing common salt into the fire during the burning process. When the vapors rise and come into contact with the surface of the brick, a chemical reaction takes place which produces the desired effect. Wall tile, pottery, plumbing ware, and other clay products in which a colored or other high-grade finish is desired are glazed by treating their surfaces with a special wash and burning a second time. The wash is composed usually of clay, feldspar, ground quartz, and boric acid. Metallic compounds are used to produce colors in glazes similar to those produced in glass.

Enamels are essentially glass which has been fused to a metal surface. Regular and acid-resisting enamels are applied to sheet iron and cast iron for use in making stove frames, refrigerator cabinets, and plumbing ware. Enamelware is easy to keep clean, but it chips and breaks like glass. Never wash porcelain finishes while they are warm. Remove discolorations promptly using soap and water; never use harsh cleaning powders containing grit or acid.

• MISCELLANEOUS MINERAL PRODUCTS

The rock-fiber mineral, asbestos, occurs in thin veins in rock. There are small but valuable deposits in Arizona, but the most important are in Quebec. After blasting and crushing the asbestos rock, the tiny fibers are extracted by conveying the crushed rock past a machine that acts much like a huge vacuum sweeper, removing the asbestos fibers and leaving the worthless, rock materials. Asbestos fibers are fireproof, do not conduct electricity, and have a tensile strength (resistance to being pulled in two) up to 400,000 pounds per square inch. These properties lead to dozens of uses for asbestos materials.

Asbestos fabrics are made in the same way as cotton ones—the fibers are carded, rolled into roving, spun into yarn, and woven into cloth. Such cloth is made into clothing for firemen. Asbestos brake linings and clutch facings are woven on special looms. Asbestos paper is likewise made in the same way as the ordinary kind—



Courtesy Johns-Manville Company

A fire fighter's suit is made from asbestos cloth to protect against open flame and heat.

asbestos replacing the wood pulp (see p. 431). When crimped and rolled, it produces a convenient and effective insulation material for steam pipes. Asbestos paper treated with asphalt is used in roofing. Floor tile of beauty and durability in a wide range of size and color is made from a mixture of asbestos and asphalt.

Combined with Portland cement, asbestos finds its most extensive uses in industry and the home. The wet mix is built up on a steel form and compressed by hydraulic machines to make corrosion-resistant pipe for water mains, sewer pipes, electric conduits, flues, vents, and stacks. For roofing and siding material which is fireproof and which combines lasting strength and toughness, asbestos cement is compressed into corrugated forms; when pressed into flat sheets, it finds use as wall board in offices, ships, bathrooms, and kitchens. Asbestos-cement shingles with the wood grain impressed on one surface are used for roofing and siding, affording excellent protection against weather and fire.

Magnesium carbonate occurs abundantly in a mineral form known as magnesite. Like calcium carbonate, it is decomposed by heat:

magnesium carbonate → magnesium oxide + carbon dioxide

$$MgCO_3 \rightarrow MgO + CO_2\uparrow$$

Magnesium oxide is commonly known as *magnesia,* and it finds many uses in building and industry. Combined with about 15 per cent asbestos, it is formed into insulating blocks for boilers, oil stills, high-temperature furnaces, etc. Fire brick for the interior linings of furnaces may also be made of magnesia. In the building

industry, magnesia is mixed with magnesium chloride, asbestos or wood fibers, and water, forming a plastic mass which sets to a hard, rocklike product useful as stucco, flooring material, and the like.

Two chief kinds of mineral wool are made in this country. One common kind is made by mixing certain kinds of stone, principally phosphate rock, with molten blast-furnace slag and converting the entire mass into a fibrous state by blowing it under tremendous pressure into a cooling chamber. Another kind of mineral wool is made in similar manner from selected granite rock heated to about 3000° Fahrenheit; the product is called *rock wool.*

The greatest value of mineral wool lies in its use as an insulator for heat and as a protector against fire. Its insulating qualities are due to the innumerable air cells formed by the mass of pliant, glassy fibers interlacing in all directions. Being noncombustible itself, mineral wool greatly retards the burning of wooden floors and partitions if the enclosed spaces are filled with it. In addition, mineral wool is durable and will not decay, become musty from dampness, or become infested with vermin. It is very useful for insulating the outside walls and roofs of dwellings against the heat of summer and the cold of winter, for insulating ovens on kitchen stoves, for protecting water pipes in exposed partitions from freezing, and for chinking around chimneys where they go through the roof—to mention just a few of the many applications of this wool made from rock.

Asphalt, or asphaltum, has been used throughout the ages in construction. It finds use as a mortar, for flooring purposes, and wherever a waterproofing agent is needed—as in roofing, building cisterns for storing water, and making ships watertight. Asphalt is found in extensive lakelike deposits, notably in Trinidad and Venezuela. Deposits also occur in Cuba, Mexico, Utah, and various other parts of the United States. Several varieties of asphalt from different sources are on the market, and, for certain purposes at least, asphalt made from petroleum is a competitor of the natural mineral. When petroleum with an asphalt base is distilled almost to dryness, nearly pure asphaltum remains in the still. Other names for asphaltum are pitch, tar, and bitumen.

The uses of asphalt are numerous and varied and likewise well known: asphaltum paints and varnishes; a binder in road building; a waterproofing agent for basement walls; roofing paper and shingles; flooring materials—these are a few of its applications. Asphalt paper is made by saturating the proper grade of paper with hot asphalt and pressing it between heated rollers. Asphalt roofing

shingles are made in similar fashion, except that the surface is later coated with slate granules and rolled again, after which the shingles are cut to size and shape.

Exercises for Problem Study and Review

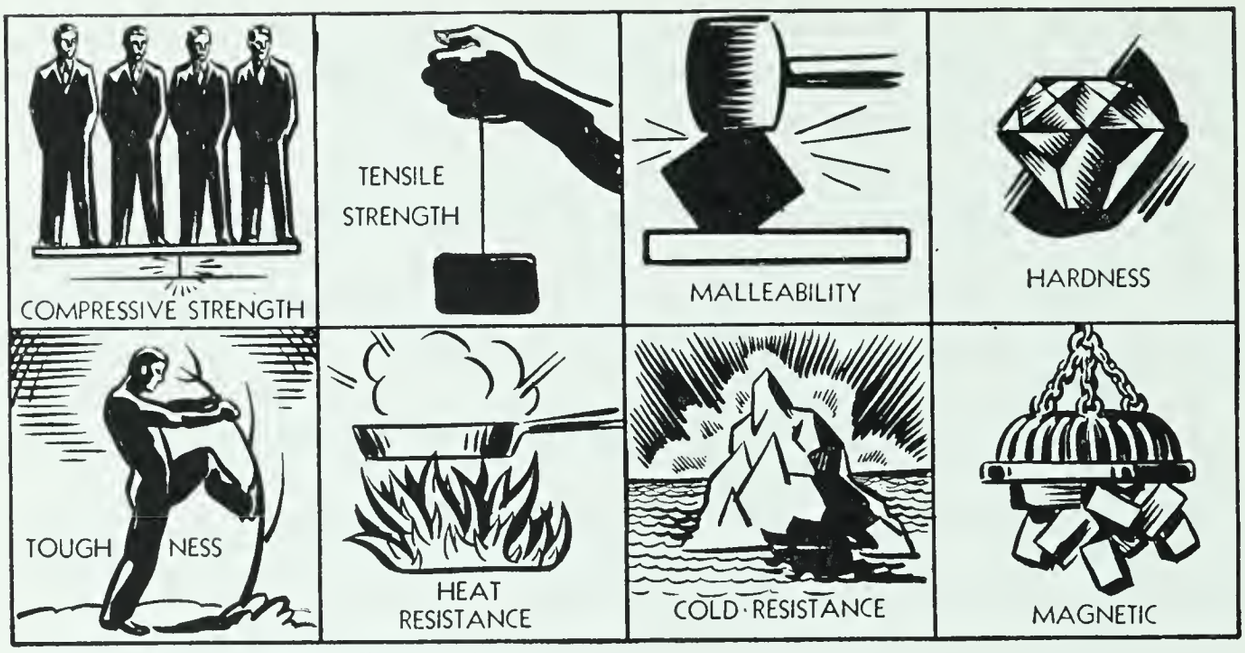
1. Outline the extensive role that limestone and limestone products play in construction. Gypsum and its products.
2. How is cement made?
3. Compare the hardening process for ordinary mortar with that for plaster of Paris and concrete.
4. What uses for glass make it indispensable to modern civilization?
5. There are many kinds of glass. What property or properties determine the use or uses for each kind?
6. What are the distinctive properties and resulting uses for asbestos?
7. How do you account for the effectiveness of rock wool and similar insulation materials?
8. Would you expect natural asphalt to be very similar to that obtained from petroleum? Explain.
9. Would a considerably higher or lower melting point make asphalt more or less desirable for its present uses? Why?

Problem 2: How are the common metals obtained and prepared for use?

• FROM ORES TO METALS

Imagine, if you can, a world without metals or even a world without one particular metal—iron. To do so we would have to turn our minds back to prehistoric time, back to the old Stone Age. The significance of metals to human activity and progress is indicated by the fact that the Bronze Age took its name from man's use of this metal, which he made by mixing copper and tin. Later the discovery of iron ushered in another great era in the history of mankind—the Iron Age.

About two dozen metallic elements serve modern needs, but over five thousand mixtures of metals, called alloys, are known. Iron still forms the backbone and sinews of our machine age, and copper makes up the nerves of our vast electrical-communication and power-transmission systems; but other metals, many of them rarer and more precious than gold, are essential to this modern age of automobiles, airplanes, lightweight and streamlined trains,



Courtesy General Motors Corporation

Uses for metals are determined by their properties.

radios, and television. Fulfillment of these needs has resulted from the rapid advances of *metallurgy*—the science of extracting metals from their ores and adapting them to use. Day after day, research metallurgists painstakingly carry on their investigations to make metals more useful to mankind.

Metals are useful because of their wide range of properties. For the most part, they are heavy, bright, shiny solids which resist fire, are good conductors of heat and electricity, and are malleable and ductile—that is, they can be hammered into thin sheets and drawn into fine wire. Gold can be beaten into sheets one three-hundred-thousandth of an inch thick, and platinum can be pulled through a die to form wire only three one-hundred-thousandths of an inch in diameter. Other important physical properties which all metals possess to some degree are hardness, toughness, tensile strength, resistance to pressure, and resistance to cold.

Notable extremes and exceptions to the general rule among metals are to be found. At usual temperatures, all metals are solids except mercury, and their melting points range from that of mercury, 38.9 centigrade degrees below the freezing point of water, to that of tungsten, 3370 centigrade degrees above. Most metals are many times as heavy as water, but lithium, sodium, and potassium float on water like cork; osmium is the densest element known, being 22.5 times as heavy as water. Magnesium is a metal that will burn in air like paper, while aluminum foil or wire sealed in a bulb filled with oxygen burns to provide the intensely bright light used in photography.

Most ore deposits consist of a mixture of ore and worthless earthy material known as gangue. Methods for separating these two types of materials have been devised. In one older method known as *gravity separation,* the ore is crushed and treated with running water. This allows the heavy ore-bearing lumps to settle and the lighter particles of gangue to be washed away.

Today, more ores are treated by *flotation* than by any other method. In flotation, the heavy ore particles are caused to float, while the lighter gangue settles. This seeming reversal of the law of gravity is accomplished by finely crushing the ore, mixing it with water to which certain chemicals and oils have been added, and then bubbling in air or other gas. A froth is formed, and the tiny gas bubbles attach themselves to the ore particles but not to the gangue. The bubbles float the pieces of ore to the surface of the container, while the worthless gangue is removed at the bottom.

After the ore has been mechanically concentrated, the actual liberation of the metal is brought about by chemical means. Energy in some form, usually heat or electricity, is required, and several types of furnaces have been designed for this purpose.

Oxide ores are composed of metals firmly combined with oxygen. When iron is exposed to moist air, iron rust or iron oxide, as the chemist calls it, is formed. Other metals behave in a similar way. To obtain metals from oxide ores, we must reverse the rusting process—that is, we must find some way to take the oxygen away and leave the metal free. To understand how this is done, we must first study a little chemistry.

Many elements unite with other elements to form new substances called *compounds.* Oxygen is considered very active, because it unites readily with many other elements. When it combines with hydrogen, as it does during the burning of gasoline, water is produced. This is evident on cold mornings when we see steam issuing from the exhaust pipes of automobiles. Oxygen combines with the carbon of wood, coal, and other fuels being burned to form carbon dioxide. The chemical union of oxygen with other elements is called *oxidation.*

Oxygen combines more readily with some elements than with others. In a furnace, it combines with the fuel instead of the grates and sides of the furnace, which shows that it combines with carbon more readily than with iron. This fact is used to advantage in obtaining metals from oxide ores. The oxygen in such ores is caused to leave the metal and transfer to another element with which it forms a firmer union. Generally, the second element used is carbon in the form of coke, although sometimes other

metals are used. This method is illustrated by the following equations:

ore	coke	metal	
iron oxide +	carbon →	iron +	carbon monoxide
Fe_2O_3	3C	2Fe	3CO

zinc oxide	carbon	zinc	carbon monoxide
ZnO +	C →	Zn +	CO

chromium oxide	aluminum	chromium	aluminum oxide
Cr_2O_3 +	2Al →	2Cr +	Al_2O_3

The removal of oxygen from compounds, as from the oxides of iron, zinc, and chromium, is called *reduction*. Reduction reactions are carried out at high temperatures, leaving the liberated metals in the liquid state.

Some metals cannot be extracted from their ores by reduction with carbon because they form a firmer union with oxygen than they do with carbon. Aluminum, sodium, potassium, calcium, and magnesium are examples. Electricity is used to free these metals from their ores. The ore is properly treated so that it can be melted or put into solution; then a direct current of electricity is passed through it. The metal deposits at the negative electrode.

Low-grade ores, as well as some difficult to reduce, may be treated with chemicals to put them into solution. After this, the metal may be obtained by immersing in the solution another metal which is more active. The principle involved in this method is readily demonstrated by inserting for a few minutes the clean blade of a pocketknife into a solution of copper sulfate. Iron is more active than copper and displaces it:

copper sulfate +	iron →	iron sulfate +	copper
$CuSO_4$	Fe	$FeSO_4$	Cu

• FROM IRON ORE TO PIG IRON

Some idea of the importance of iron may be gained from the facts that its annual production in the United States is measured in millions of tons and that the annual output of iron exceeds the combined total of all other metals, both in tonnage produced and in value. We need think only of the many uses of iron to realize our extreme dependence upon this metal. The framework of great buildings, the structure of bridges, the rails for railroad transpor-

tation, and the materials for hundreds of kinds of products from kitchen knives to battleships or ocean-going liners, as well as the tools and machinery necessary for their manufacture, are just a few instances of the many applications of iron. Because of its usefulness and its vital role in modern civilization, we shall consider in some detail the metallurgy of iron.

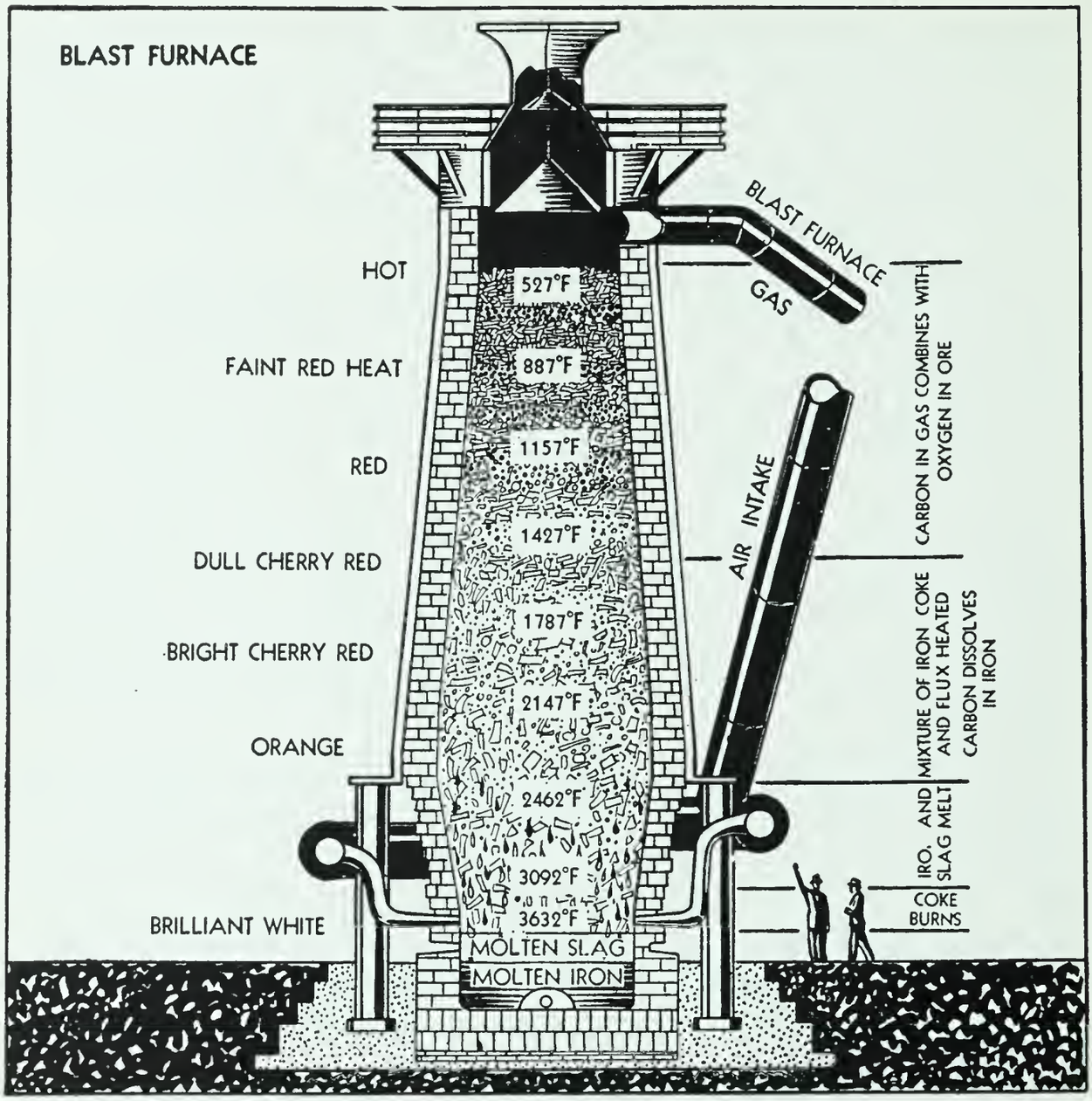
Iron ranks fourth in abundance among the ninety-two known chemical elements. It is exceeded only by oxygen, silicon, and aluminum. On the surface of the earth, iron is found chiefly as iron oxide mixed with rocks, other minerals, and earthy material.

Iron-ore deposits occur on every continent and in almost every country. It is obtained in twenty-eight of our forty-eight states and has been found in all of them, but the chief ore deposits that we use today are in the Lake Superior region, which includes Michigan, Wisconsin, and Minnesota. The Mesabi Range in Minnesota yields a high-grade ore containing about 55 per cent iron. In some European countries, ore containing only about 25 per cent iron is used.

The Mesabi deposit has the particular advantage of lying near the surface of the earth, which makes possible mining it with steam shovels by *open-pit* mining. The ore is hauled by rail to upper Lake Superior ports, whence lake freighters carry it to ports along the lower Great Lakes where blast furnaces are located—notably Chicago, Gary, Cleveland, Buffalo, and Erie. Railways transport ore to inland centers, such as Pittsburgh, Pennsylvania, and Wheeling and Weirton, West Virginia.

Iron is extracted from iron ore by reduction in a blast furnace. The blast furnace is a huge steel tower about one hundred feet high and twenty-two to twenty-five feet in diameter at its widest part. It is lined with firebrick. Near the bottom of the furnace are pipes to admit the forced blasts of air, from which the furnace takes its name.

The *charge* is admitted through a hopper arrangement at the top of the furnace. The charge consists of limestone and a mixture of iron ore and coke in proper amounts, which are introduced in successive layers. As the charge descends slowly downward, it is subjected to the increasingly high temperatures produced by the burning in the furnace. As the coke burns, it takes oxygen from the iron ore, thus reducing it to iron and forming gases which escape through a flue near the top of the furnace. The released iron is in a liquid state, and it trickles down into a collector at the bottom of the furnace. The limestone acts as a *flux,* combining



Courtesy General Motors Corporation

with some of the impurities in the iron ore and making them liquid. This liquid also falls into the collector, but since it is less dense than iron, it floats on top of the pool of iron as *slag*.

As one charge of ore, coke, and limestone is consumed, another is fed in at the top. The molten iron and slag are drawn off about every four hours. Once started, a blast furnace may operate continuously until it needs repairs. One furnace may produce as much as seven hundred tons of iron daily.

The metallic product of the blast furnace is known as pig iron. Its composition varies according to furnace conditions and the raw materials used, but it is characterized chiefly by containing from 2.5 per cent to 4 per cent carbon, which it absorbed in the furnace. The following analysis indicates what pig iron contains beside iron:

Carbon	3.50%
Manganese	2.00%
Sulfur	0.04%
Phosphorus	0.30%
Silicon	1.25%

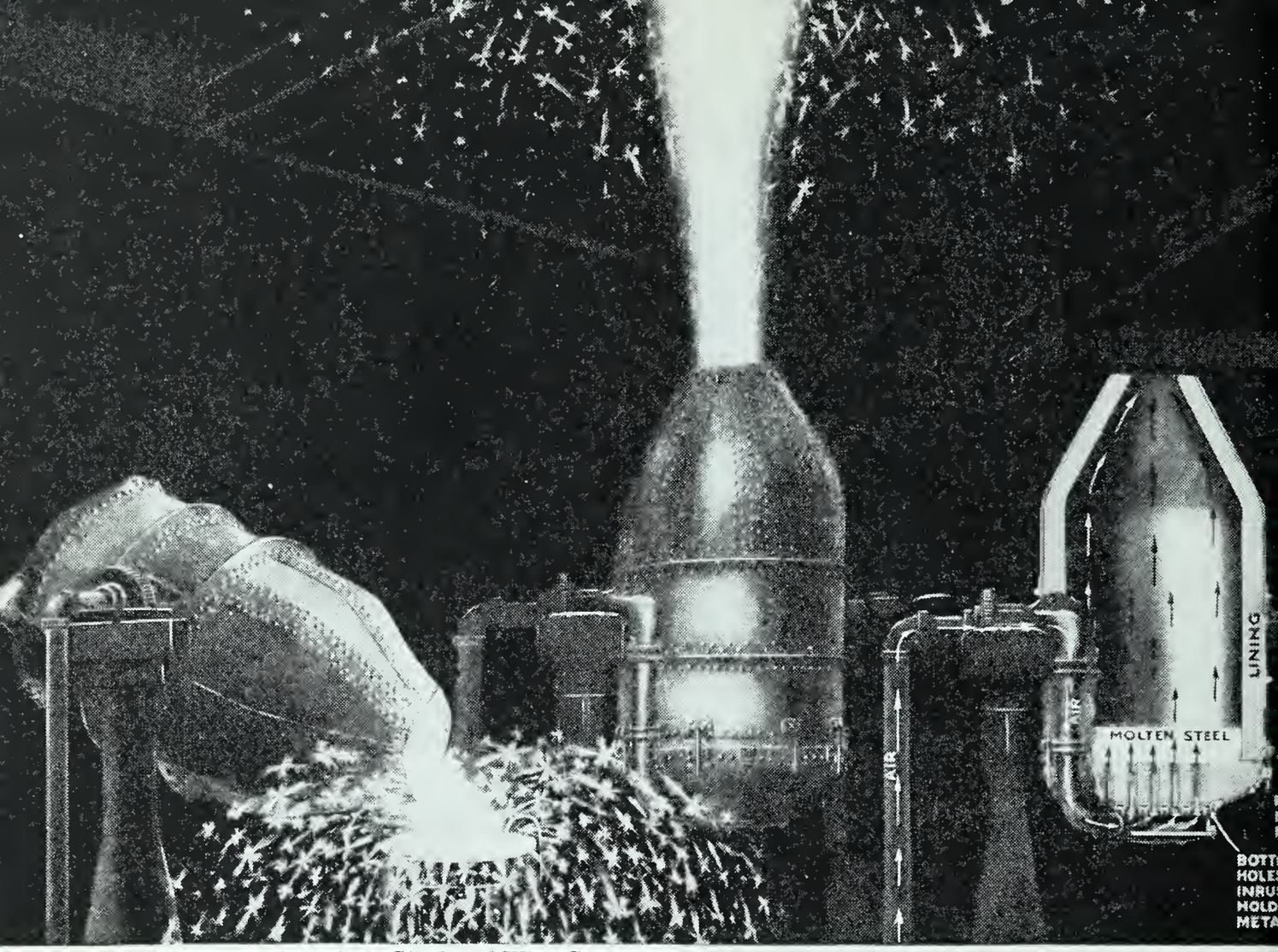
Pig iron cannot be rolled, forged, or welded, but it can be melted and cast. Objects made of it are brittle and hard, have little tensile strength, and cannot withstand sudden shocks or stresses. It is used for castings only where strength is not of great importance.

In making *cast iron,* pig iron along with scrap steel and old cast iron is remelted in another furnace. It is cast in sand molds, somewhat in the same manner that gelatine desserts are made in molds. Upon solidifying, cast iron expands and gives sharp edges to the castings. Cast iron is used for making stove parts, steam radiators, automobile-engine blocks, brake drums, and pistons.

Malleable iron is made from cast iron of special composition. Malleable means capable of being hammered or rolled without breaking. The castings are made in the usual way, but after removal from the molds they are given a special heat treatment which completely changes the properties of the iron. They are packed in iron drums and heated to about 1700° F. for a long time; then they are slowly cooled. This treatment is called *annealing* and requires from two and one half days to a week.

When the castings go into the annealing furnace, they are so hard and brittle they can be broken with a hammer. When they come out they will withstand a great deal of hammering and are so soft they can be bent almost double before breaking. Yet the outside appearance of the castings is the same. Malleable iron is used in making objects of such complicated shapes that they must be cast and still possess great strength. In automobiles, for example, malleable iron is used to make wheel hubs, clutch and brake pedals, and spring hangers.

Small amounts of pig iron are used to make wrought iron, one of the purest grades of commercial iron. It contains very little carbon and is soft and pliable, being well adapted to the making of nails, wire, water pipe, and chains. Since it is easily magnetized and demagnetized, it is used to make cores for electromagnets. Wrought iron for these and other purposes, however, is rapidly being displaced by soft steel, which has almost identical properties and can be made more cheaply.



Courtesy American Steel and Wire Company

The Bessemer converter takes from nine to fifteen minutes to change molten pig iron into steel.

• FROM PIG IRON TO STEEL

The uses of pig iron just described, while important, consume only a small percentage of all that is manufactured. More than three-fourths of the pig iron produced is used in making various grades of steel. It has been said of steel that we could give up any other metal with less effect on our civilization. It is more important in modern life than gold, silver, lead, copper, and tin combined; it is our most valuable form of iron.

The reason for the eminent role of steel is the wide range of properties which different kinds of steel possess. Steels are our strongest materials. The tensile strength, or resistance to pull, varies from about 40,000 to more than 500,000 pounds per square inch, depending on the kind of steel. It is the most important metal which can be hardened by sudden cooling from a high temperature. Steels can be made so soft they can be scratched with a needle or so hard they will scratch glass. They can be given a hard surface to resist wear, and a tough, soft core to give ductility. Steels can operate at temperatures varying from 250 degrees below zero, Fahrenheit, to a cherry-red heat. They can be easily cut,

welded, bent, or pressed without destroying their other desirable properties. And for good measure, steels have magnetic properties which make them useful in electrical machinery.

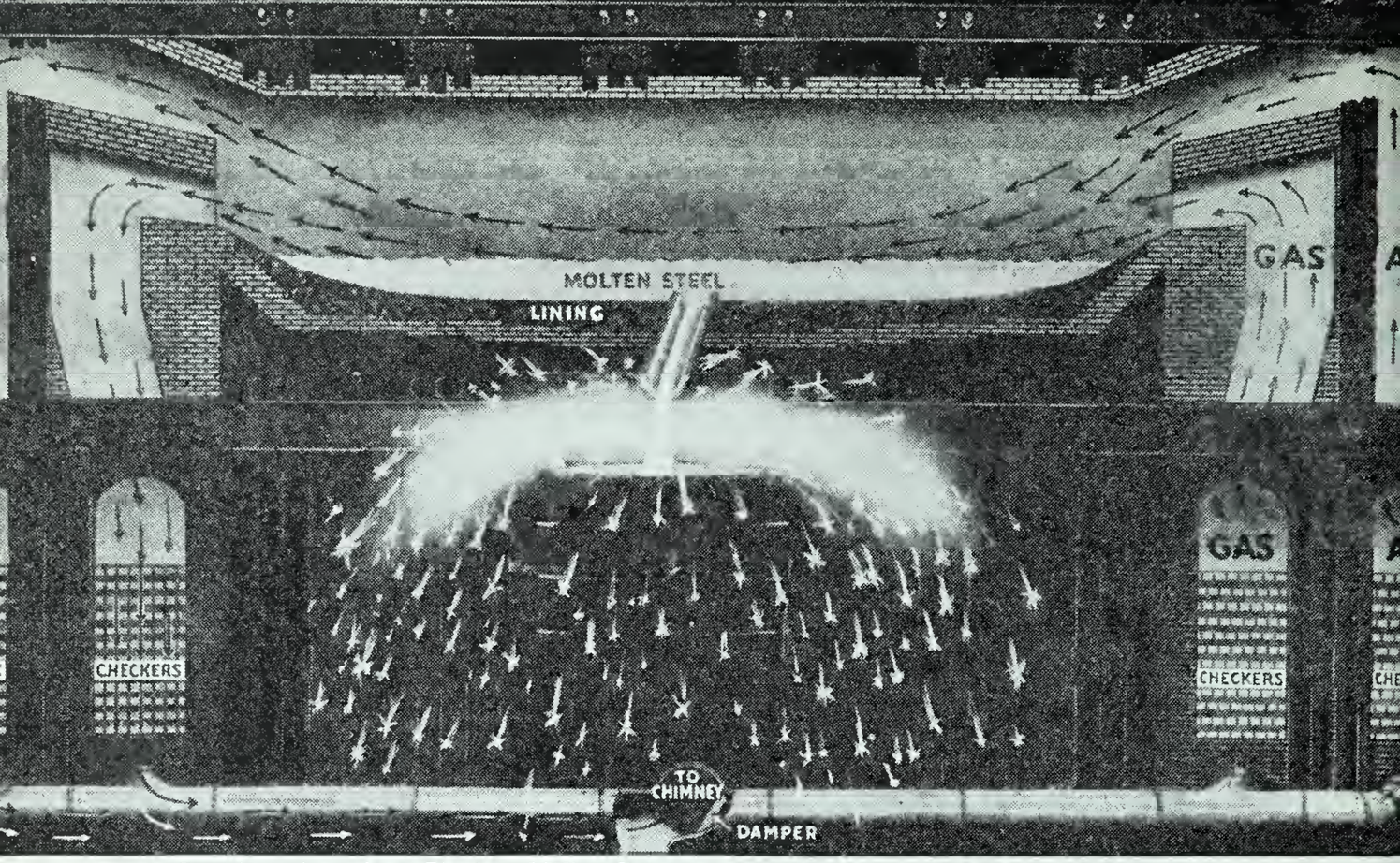
Steel is a form of iron in which the amount of carbon varies from about 0.2 to 2.0 per cent. Pig iron, from which most steel is made, usually contains much more than this per cent of carbon. Consequently, the process of *making steel consists essentially of taking the excess carbon out of pig iron.* At the same time, other impurities are eliminated or controlled within definite limits, depending on the kind of steel desired. The properties of the resulting steel depend partly upon the percentages of carbon and other elements it contains and partly upon any special heat treatment given to it later.

There are three chief methods used today for making steel. They are the *Bessemer process,* the *open-hearth process,* and the *electric-furnace method.* Credit for devising a successful commercial process is usually given to Sir Henry Bessemer, born in 1813 in England of French parents. His interest in iron and steel came about after he had been called upon to aid in the development of guns and projectiles. He proposed very powerful projectiles, which made the cast-iron cannon then in use unsuitable. He therefore tried to develop a stronger material for his guns.

After several years of experimentation, Bessemer found that blowing air through molten cast iron or pig iron made the iron hotter, whereas everyone had thought that a draft of cold air bubbling through molten iron would cool it. Bessemer concluded correctly that the carbon and other impurities in the iron were literally burned out of the white-hot metal by this treatment. He announced his discovery before a meeting of the British Association on August 11, 1856, in a paper entitled "The Manufacture of Malleable Iron and Steel Without Fuel."

In the United States, William Kelly, of Eddyville, Kentucky, had also developed a similar process. When he heard that the United States patent office had granted Bessemer a patent in 1856, Kelly was able to prove that he had made steel by blowing air through molten pig iron several years before Bessemer and also obtained a patent in 1857. So you see, man has been making steel in large quantities for somewhat less than one hundred years.

The Bessemer converter, as the furnace is called, is a large egg-shaped container open at the top and lined with a special kind of firebrick. From fifteen to twenty-five tons of molten pig iron are poured into the converter, and a blast of hot air is forced into the



Courtesy American Steel and Wire Company

This diagram shows the principle of the open-hearth furnace. The direction of the incoming and exhaust gases is reversed periodically in order to increase efficiency by preheating the incoming mixture of gas and air by contact with the hot checkerwork.

charge through openings in the bottom of the furnace. The molten iron has a temperature of about 2200° F. when poured in, but, within a few minutes after the air blast is turned on, the burning of the impurities in the iron raises the temperature to about 3500° F. Most of the impurities are burned out. This burning causes the mouth of the furnace to belch forth a shower of sparks and long tongues of bright flames, thus producing one of the most spectacular sights in the steel industry. The "blow" is complete in ten to fifteen minutes.

When the impurities are burned out, correct amounts of carbon and manganese are added to give the steel the final composition desired. The steel is then poured into molds where it solidifies into *ingots* ready to be made into shapes suitable for use.

At the present time, more steel is made by the open-hearth furnace than by any other process. Its first use was in England in 1863. The open-hearth furnace uses heat from an outside fuel source—namely, producer gas. Two openings at each end of the furnace admit gas and air through separate channels. When the air and gas come together over the molten metal, burning occurs, and the heat is reflected downward upon the charge from the roof of the furnace. The charge consists of pig iron, scrap steel, and other necessary materials. It is contained in the huge basin-shaped

hearth of the furnace, which may hold as much as 250 tons of material. By means of the high temperature created over the metal in the furnace and by the action of the materials added along with the pig iron, the excess carbon is effectively burned out and other impurities in the iron are removed. This process of making steel requires about twelve hours for completion.

An important feature of the operation of the open-hearth furnace is the utilization of heat from the escaping gases to preheat the air and gas which enter the furnace. For about twenty minutes, air and gas enter at one end of the furnace and are burned. The hot gases which result from the burning are caused to escape at the other end through a checkerwork of firebrick, heating it to a high temperature. Then the direction of incoming and escaping gases is reversed. By this procedure, the incoming gas and air are preheated by contact with the hot checkerwork, while the escaping gases begin heating the checkerwork at the other end of the furnace. Preheating produces a much higher temperature than would be obtained if cold air and gas were used to produce combustion over the pool of liquid metal; in addition, it results in a large saving of fuel.

Although the open-hearth process is slower and more expensive than the Bessemer process, it has the advantages of losing less steel, yielding cleaner steel, and allowing a more careful check on the quality of steel being produced. When test samples show the steel to be of correct composition, the furnace is tilted, and the steel is poured out into ingots. Pig irons unsuited to the Bessemer process can be made into steel in the open-hearth furnace, and sometimes steels made by the Bessemer converter are further purified by this process.

The highest quality steels produced today are made in the electric furnace. The charge varies from about three to fifteen tons and consists usually of the same materials that are used in the open-hearth furnace; namely, pig iron, scrap steel, a small amount of iron ore, and limestone as a flux.

The outstanding characteristic of this type of furnace is the use of electricity as the source of heat. A heavy current is introduced by means of carbon electrodes which penetrate only the slag. The heat produced by the resistance to the flow of current is sufficient to melt the charge.

The chief advantages of the electric furnace are: (1) the chemical reactions take place in nonoxidizing conditions; (2) no outside impurities are introduced by a fuel; (3) temperature and melting

conditions can be carefully controlled. High-grade steels from the electric furnace are used for making fine-edged tools, cutlery, pen points, razor blades, and watch springs, as well as for many larger objects and structures.

• METALS FREED BY ELECTRICITY

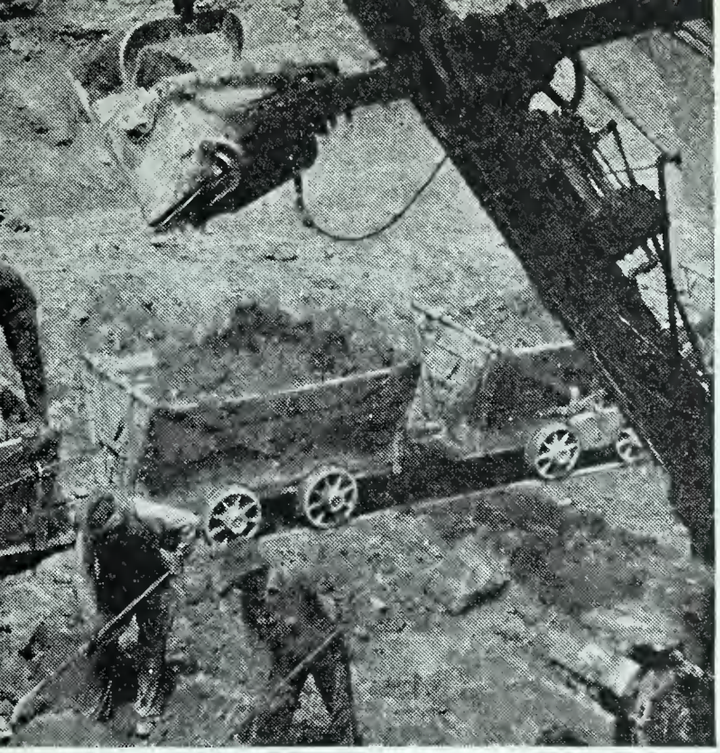
The story of iron illustrates the principles of the chief method of winning metals from their ores—by reduction with carbon. The story of aluminum explains the principles involved in extracting metals by the second most important method—electrolysis. Among the other metals obtained in this fashion are sodium, potassium, calcium, barium, and magnesium. In addition, several metals, notably copper and nickel, are purified by electrolysis. At this time, it is advisable to review the explanation of electrolysis beginning on page 150.

How to obtain aluminum in large amounts and at low cost remained for many years an unsolved problem. Professor Frank Fanning Jewett, who was head of the chemistry department of Oberlin College in Oberlin, Ohio, helped provide the inspiration which started one of his own students on the successful quest toward a solution of the problem. That young college student was Charles Martin Hall.

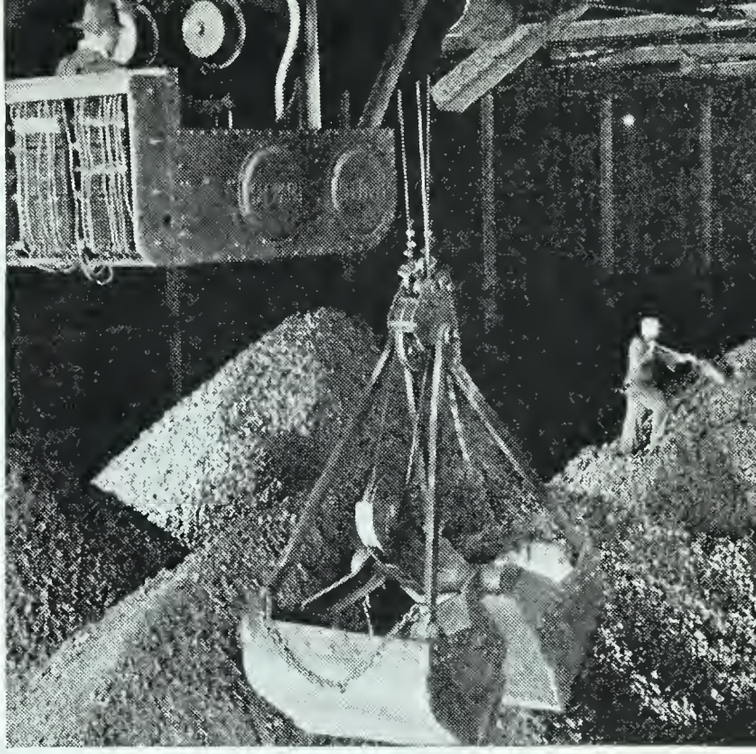
Aluminum makes up about 8 per cent of the earth's crust. It is the third most abundant element, being surpassed only by oxygen and silicon, and is the most plentiful of all the metals. However, it is found only in compounds. Although widely distributed in clays, feldspars, and other minerals, there is no practical method by which aluminum can be extracted from these materials.

Aluminum was first isolated in 1825 by Hans Oersted, a Danish scientist, but in 1852 it was still regarded as a rare metal, and the price was more than $500 a pound. Working with crude materials in his father's woodshed, Hall in 1886, at the age of twenty-two, devised a practical electrolytic method for separating aluminum from its compounds. In five years, Hall's process brought the price of aluminum down to less than a dollar a pound. Today, aluminum sells for about fifteen to twenty cents a pound.

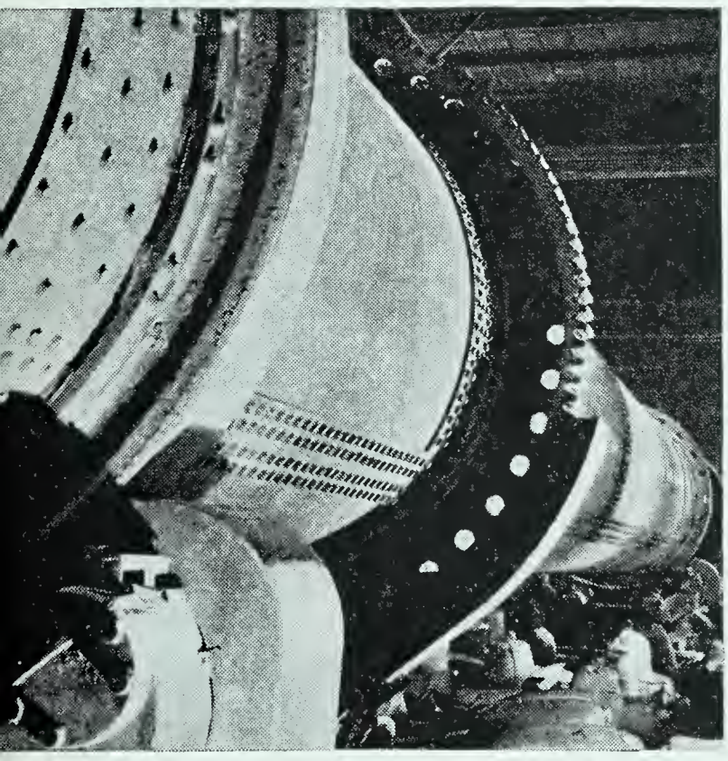
Hall had difficulty in securing financial backing necessary for the production of aluminum on a large scale, but he eventually succeeded and became not only famous but very wealthy. At his death he left his fortune to religious and educational work, both in this country and abroad. He bequeathed one-third of his estate to Oberlin College, his alma mater.



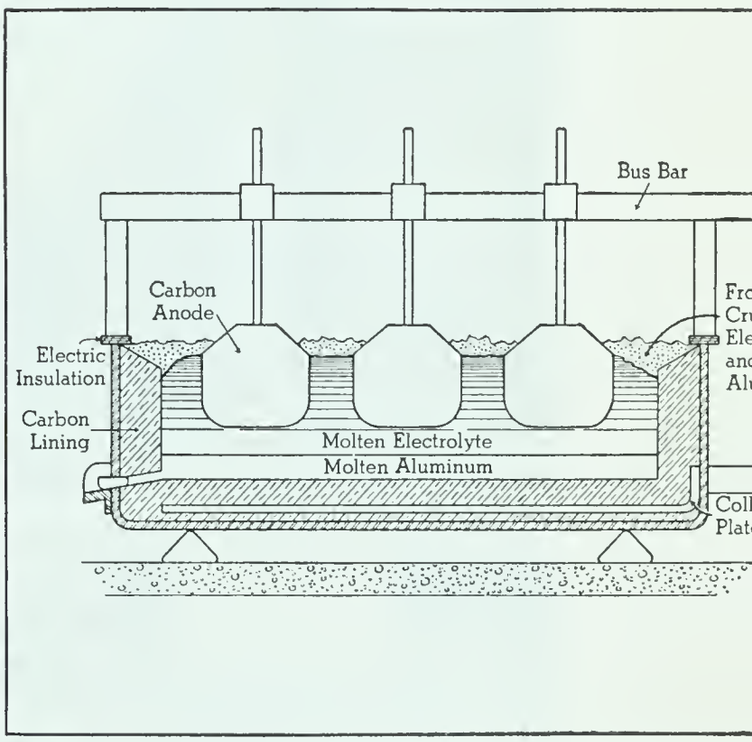
The ore bauxite is taken from the earth to be converted into aluminum.



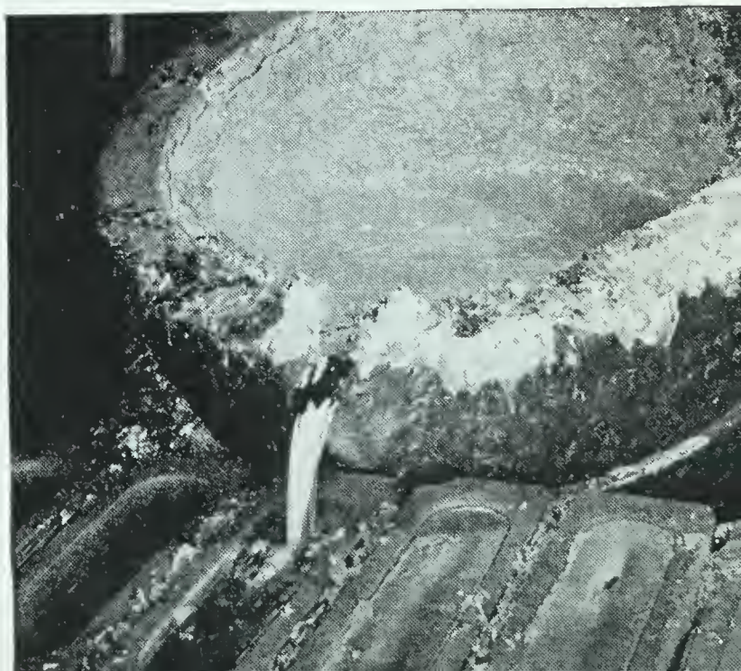
The ore is crushed and then stored in piles until needed.



Heating the bauxite is one step in forming a new compound called alumina.

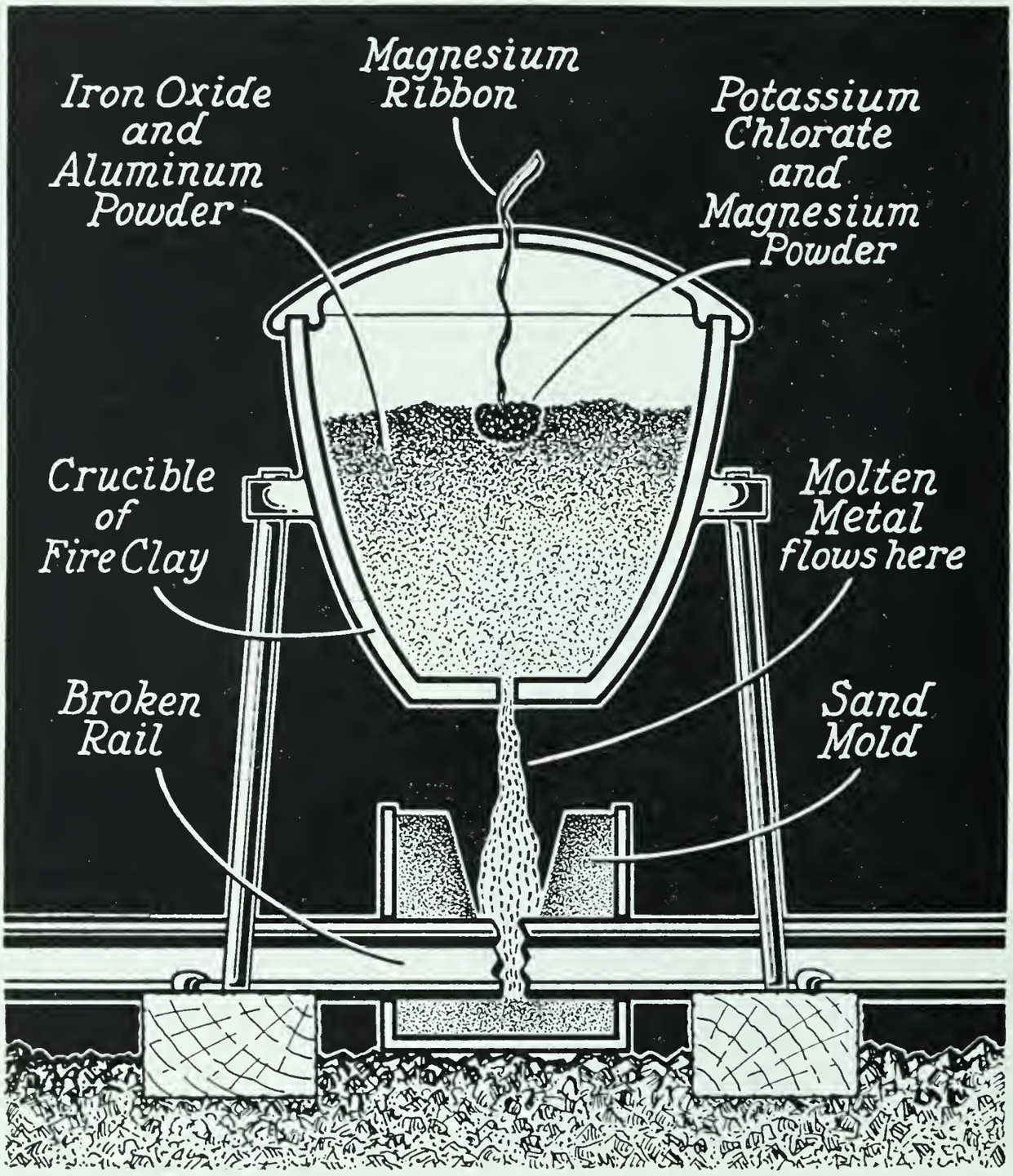


In this electrolytic cell, aluminum is liberated from the alumina.



The hot, liquid aluminum is cast into bars known as "pigs."

Courtesy Aluminum Company of America



Describe the chemical action that follows when the magnesium-ribbon fuse is ignited. How is this reaction applied in the incendiary bomb?

It is interesting to note that a young French scientist, Paul Héroult by name, independently and in the same year discovered the same principle as Hall. Hence, this method of extracting aluminum is known as the Hall-Héroult process. This process is employed in the modern aluminum industry, making possible the extensive uses of aluminum as we know them today.

The extraction of aluminum consists of purifying the ore and then freeing the metal by electrolysis. The ore used is *bauxite,* a particular kind of aluminum mineral found principally in Ar-

kansas. In addition, the process requires *cryolite,* an aluminum mineral found naturally only in Greenland but now possible to produce by chemical manufacturing processes.

The cell in which the extraction is accomplished is an iron tank lined with carbon; it acts as the cathode during electrolysis. Carbon rods suspended in the cell act as anodes. Cryolite is put into the cell and melts when the current passes through it. The purified ore, known as alumina, Al_2O_3, is then added and dissolves in the melted cryolite. As the heavy current continues to flow, molten metallic aluminum is formed at the cathode; it settles to the bottom of the tank and is removed from time to time. The oxygen of the alumina combines with the carbon of the anodes to form gaseous oxides of carbon. Alumina is added from time to time to keep the process continuous; the cryolite is not used up.

In addition to its well-known uses in aircraft, thousands of applications of aluminum have been listed, and new ones are continually being found. One of the most interesting uses of aluminum is in *thermit welding.* Thermit consists of a mixture of iron oxide and aluminum powder. When ignited, this mixture undergoes vigorous chemical change during which oxygen transfers from iron to aluminum and much heat is liberated:

$$\overbrace{\text{iron oxide} + \text{aluminum}}^{\text{thermit}} \rightarrow \text{aluminum oxide} + \text{iron} + \text{Heat}$$

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe + \text{Heat}$$

The temperature reached is sufficient to melt the iron. Thermit is used to weld broken propeller shafts, rails, rudder posts, and heavy machinery that cannot be conveniently moved. The method by which thermit welding is done is illustrated in the drawing. The thermit reaction is also used in incendiary bombs.

• METALS MADE TO ORDER

Metallurgists have developed methods of extracting from minerals of the earth many different metals with a great variety of properties. In spite of this fact, however, the needs of modern civilization necessitate the fabrication of new metals with combinations of properties not offered by any one metallic element. It is rather obvious that the same metal would not be used for both the body and the steering mechanism of an automobile; for the construction of airships and for steam shovels; or for the manu-

facture of office furniture as well as for the making of jewelry. New metals made to order for special uses are called *alloys.* Their importance is indicated by the fact that this is often called the Age of Alloys.

In general, alloys are formed when two or more metallic elements are melted together and the mixture is allowed to cool and solidify. Oftentimes such nonmetals as carbon, sulfur, arsenic, phosphorus, and silicon are important ingredients of alloys. It is probable that the first alloy was prepared accidentally when the ancients reduced some ore containing more than one metal. They prepared bronze by melting together copper and tin, while brass was formed by mixing copper and zinc. Through continued research and the application of scientific principles, the preparation of alloys has today become one of the most important branches of metallurgy serving the needs of civilization.

Today's steels are really "tailor-made" alloys. The buyer specifies the kind of steel he needs, and the manufacturer, through the control of alloying elements and crystal size, gives the customer exactly what he wants. Alloy steels usually contain one or more of the following elements: vanadium, manganese, chromium, tungsten, nickel, molybdenum, and silicon. The Society of Automotive Engineers lists about seventy different kinds of steel used in automobile construction alone. This industry is the largest user of alloy steels and consumes more than one-half of all the alloy steels produced.

Vanadium imparts to steel the properties of toughness and resilience. Bars of vanadium steel are so tough that they can be tied into knots without breaking. Such steel is used in making automobile axles and locomotive parts. Chromium produces a hard, strong steel which is very resistant to wear. Steels containing this element are used to make bearings and gears for automobiles and for making projectiles to pierce armor plate. Chrome-vanadium steel is much used for leaf springs and transmission, rear axle, and steering gears in automobiles.

For dozens of years, men dreamed of a steel that would not rust. We have such steel today—not one variety but a whole series of stainless steels. Basically, they are "18-8" steels; that is, about 18 per cent chromium and 8 per cent nickel. Stainless steels can be seen in use in the turrets of battleships, the towers of skyscrapers, the blades of surgical instruments, false teeth, kitchen sinks, and a host of other products.

Molybdenum gives toughness and greater strength to steel. It

is used alone or in combination with nickel and chromium. Automobile parts, shovels, and machinery are made of molybdenum steels.

Nickel steel is especially well suited for rails, frames, and bridge construction work where great strength, toughness, and resistance to corrosion are needed. Nickel steel has almost the same composition as meteorites.

Manganese makes an extremely wear-resisting steel. It is so hard that it cannot be cut or drilled and must be ground. For these reasons, it is used to make burglarproof vaults, heavy crushing machinery, steam-shovel buckets, and armor plate.

Tungsten makes possible the so-called "high-speed steel" from which various kinds of cutting tools are made for working other kinds of steel. Hard-cutting steels can also be produced by adding chromium, vanadium, molybdenum, or manganese in the proper amount. It has been said that high-speed steels have done more to make possible the large-scale production of automobiles than any other metallurgical development. These steels retain their hardness even at red heat.

Steels containing about 2 per cent silicon and a smaller amount of manganese are sometimes used for leaf springs in automobiles. In this case, silicon confers great strength. When high percentages of silicon are used—around 15 per cent—acidproof steel is produced. It is much used for making laboratory ware and drainage pipe for chemical laboratories. This alloy is very brittle and lacks the luster typical of most metals.

Every time a new steel is developed, it gives engineers and designers additional opportunities to make their dreams come true. Streamlined automobiles with one-piece steel tops, superspeed trains, and steel that will not rust are just a few of the marvels which were dreams only a few years ago and are actualities today. They were made possible by the rapid strides of the steel industry.

Alloys in which there is no iron are termed nonferrous alloys. Brass and bronze are typical ones already mentioned. There are hundreds of nonferrous alloys; some of the better-known ones, together with their compositions, are listed in the table.

Alloy	*Elements in parts per hundred*
United States nickel coin	75 copper; 25 nickel
Bell metal	78 copper; 22 tin
Yellow brass	67 copper; 33 zinc
German silver	60 copper; 25 zinc; 15 nickel
United States cent coin	95 copper; 4 tin; 1 zinc

(Table continued on next page)

United States coin gold	90 gold; 10 copper
Sterling silver	92.5 silver; 7.5 copper
United States coin silver	90 silver; 10 copper
Shot metal	99.8 lead; 0.2 arsenic
Type metal	58 lead; 26 antimony; 15 tin; 1 copper
Plumber's solder	67 lead; 33 tin
Babbitt metal	90 tin; 7 antimony; 3 copper
Pewter	74-89 tin; 0-20 lead; 0-7.6 antimony; 0-3.5 copper and zinc
Tin foil	88 tin; 8 lead; 4 copper
Wood's metal	50 bismuth; 12.5 tin; 25 lead; 12.5 cadmium (This alloy melts at 65.5° centigrade.)
Fusible alloy	54 bismuth; 26 tin; 20 cadmium (This alloy melts at 103° centigrade.)

Light-weight alloys are of particular interest in this day and age. It is largely through the development of alloys combining great strength with light weight that rapid strides in aviation have been made possible. The chief metals in such alloys are aluminum and magnesium. Alloys of this type which have gained wide recognition are the duralumins and the Dowmetals. A representative duralumin is composed of about 94 per cent aluminum, 5 per cent copper, and very small percentages of magnesium and manganese. A typical Dowmetal might be composed of 90 per cent magnesium and 10 per cent aluminum. The gondolas of several stratosphere balloons were constructed of Dowmetal. Other types of aircraft, trolley busses, trains, truck bodies, gasoline engines, and buildings are requiring increasing amounts of light-weight alloys of aluminum. This is because they combine strength, light weight, good heat conductivity, and resistance to atmospheric corrosion.

Another method of producing metals with definite properties for particular uses is by means of special heat treatments. Heating and cooling can make great changes in the strength, hardness, brittleness, and wearing qualities of many metals. Steel is the most important metal which is heat treated.

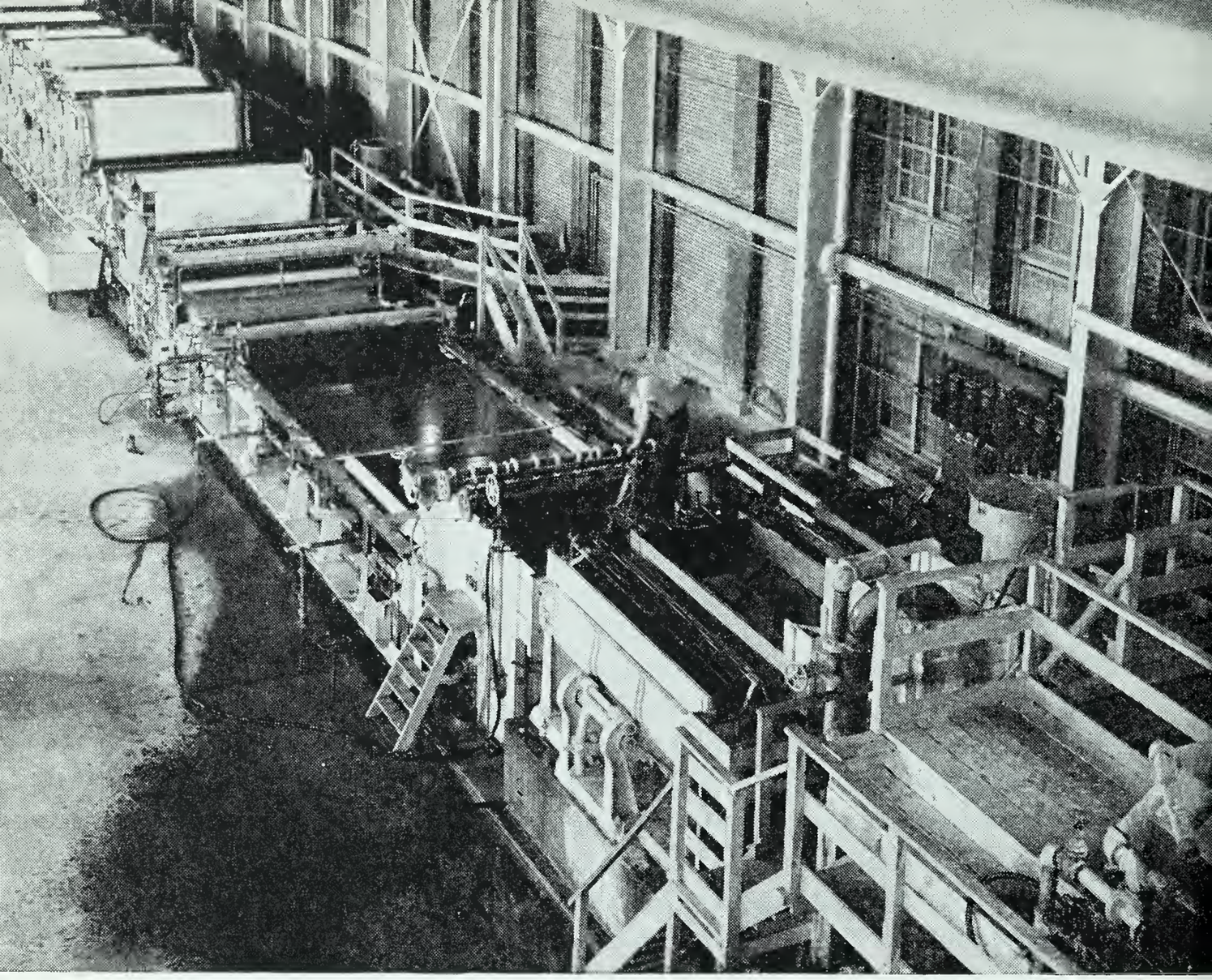
Steel is softened by annealing. The metal is heated to a bright red heat to soften it, after which it is allowed to cool slowly. This treatment relieves strains set up in the metal by other treatments and makes it soft and ductile. Probably we are all familiar with annealing. Tools, such as a knife, plane, or saw, which have gone through a fire no longer cut well. This is because they have been heated to a high temperature and cooled slowly enough to anneal the steel, making it soft.

Steel is hardened by heating to a high temperature and suddenly cooling by plunging it into cold water, salt brine, or oil. Steel is hardened to give it a good cutting edge, a good wearing surface, or great strength. Tempering is the process of obtaining the exact hardness, strength, and ductility in steel which are necessary for the work it is to do. Tempering consists of reheating a hardened steel to a definite temperature and quenching it again. The degree of hardness depends chiefly upon the temperature to which the steel is heated. Formerly it was customary to judge the temperature of the steel by observing its color during heating. Today, accurate temperature-recording devices and careful temperature control have replaced older methods of tempering steel.

Frequently, it is necessary to have a steel with a soft, tough center to give strength and also a hard, glasslike surface to resist wear. Since it is true that the higher the carbon content of steel, the greater its hardness, a hard-wearing surface is obtained by *carburizing.* An object to be carburized is put into a container and packed with carbon, which may be in the form of charcoal, charred leather, or even sugar. Heating to a white heat for a few hours results in the absorption of carbon at the surface, while the center remains soft and tough. Rear axle gears, camshafts, transmission gears, steering gears, and many other automobile parts are *casehardened,* as it is called, in this manner.

Exercises for Problem Study and Review

1. Illustrate each important property of metals using various metals that possess the different properties to a marked degree.
2. What methods are used for obtaining metals from ores? What determines the method used?
3. What combination of factors has made iron the most used metal?
4. Describe the manufacture of pig iron.
5. Compare the properties and uses of pig iron with those of malleable iron and wrought iron.
6. How does the composition of steel compare with that of pig iron?
7. What are the advantages of the Bessemer process? Of the open-hearth process? Of the electric process?
8. Describe the method for obtaining aluminum. Why is aluminum called a strategic metal? What other metals are strategic? Why?
9. What is an alloy? List five ferrous and five nonferrous alloys. Tell what elements each contains and give the specific characteristics and uses of each.
10. What is the significance of each of the following: annealing, tempering, casehardening?



Courtesy Hammermill Paper Company

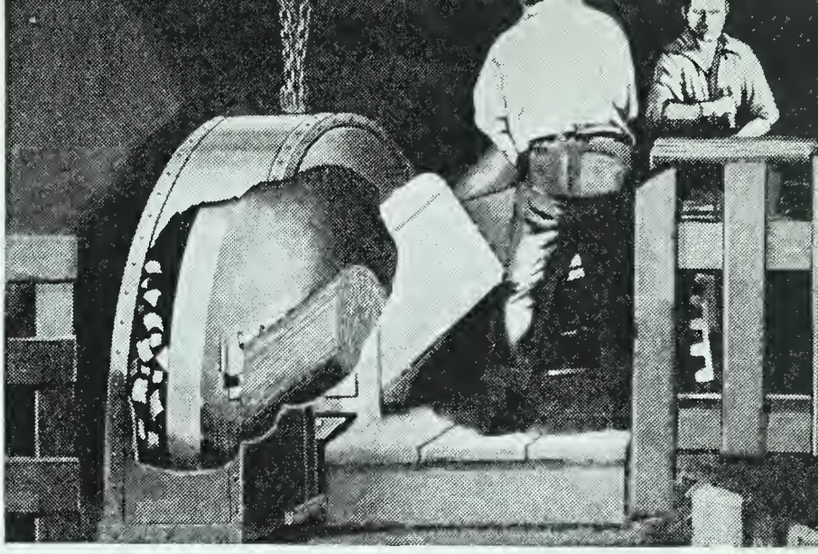
This is a paper-making machine. It changes the water suspension of prepared pulp into the finished product. Miles of paper roll from such a machine each working day.

Problem 3: How do we use plant and animal products in the manufacture of construction materials?

• FROM TREES TO PAPER

Paper is essentially a tissue composed of a large number of tiny vegetable fibers matted and interlaced to form a continuous surface. By tearing a piece of paper and examining the hairlike projections along the torn edges, you will get an idea of the size of these fibers. It has been estimated that a sheet of paper the size of the pages in this book contains more than five million such fibers.

These fibers consist of cellulose. Cellulose fibers suitable for papermaking can be obtained from many sources throughout the vegetable kingdom, such as straw, esparto grass, jute, cornstalks, and trees. The ancient Chinese are believed to have made paper



Courtesy Hammermill Paper Company

The barked pulpwood is reduced to chips as it is fed into the chipper against a seven-foot disc, fitted with four knives, revolving three hundred times per minute.

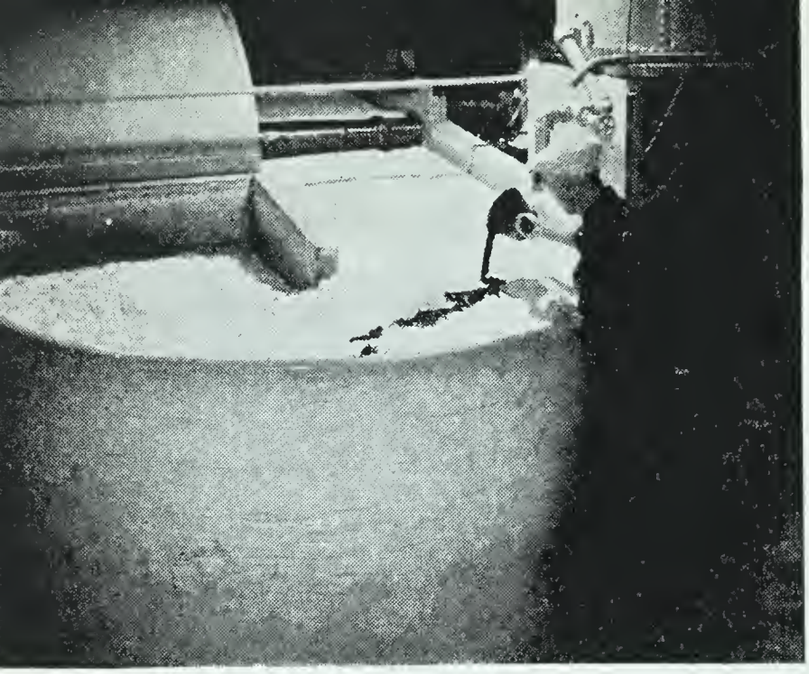
from bamboo fibers. Old linen and cotton rags have long been an important source of cellulose fibers for the paper industry and are still used in making the very highest grades of paper. About the middle of the nineteenth century, wood was introduced as a raw material in papermaking. The fact that most papers made today contain at least some wood fiber is an indication of the importance of trees as a source of supply. Spruce, hemlock, balsam, poplar, and southern pine are the chief kinds used. Southern slash pine has been acclaimed as a native source of pulp for newsprint, and a great, new industry is being hailed for the South.

The first step in making paper from wood consists of a mechanical or chemical treatment which produces pulp. In the groundwood process, logs from which the bark has been removed are pressed against a rough cylindrical stone revolving in water. The product is *mechanical pulp,* which consists of minute particles of all parts of the wood—fibrous and nonfibrous. It is used in making cheap grades of printing paper such as newsprint, but even then it is mixed with 15 to 25 per cent of *chemical pulp.*

Chemical pulp is produced by cooking wood chips under pressure in a chemical solution which dissolves the noncellulose parts of the wood and frees the cellulose fibers. It is used in making nearly all the better grades of paper.

Straw is made into a coarse pulp much used for making cardboard like that used for partitions in egg crates and for making corrugated cardboard used in packing. Old paper is also used in the manufacture of paper. Old newspapers are converted into cheap cardboard such as that used for pasteboard boxes.

After the pulp has been made, it is thoroughly washed, screened, bleached, and given special treatment to produce the kind of paper desired. The fibers are beaten, dyed, and sized. Beating reduces the fibers to uniform size, splits their ends, and softens their edges, all of which promotes matting in the papermaking machine. Dyes are added to make any desired color. Sizing produces a paper which can be written upon with ink without the ink spreading. This quality is essential for writing paper but not for



Courtesy Hammermill Paper Company

To reduce the fibers in size so they will form a firm, close sheet, the pulp is mixed with water and beaten for hours. Sizing and coloring are added in the beater.

newspaper as a special kind of ink is used. Such materials as starch, glue, casein, rosin, calcium carbonate, calcium sulfate, alum, and other chemicals are used in sizing.

After all preliminary treatments, the pulp is mixed with a large amount of water and is conducted onto the endless, moving screen of the paper-making machine. Its meshes allow the water to fall through but are fine enough to retain the fibers, which become matted together to form paper. The paper is then dried by passing it through press rollers and over steam-heated cylinders. A water suspension of fibers is fed into one end of the machine, and a continuous sheet of paper comes from the other end. Contrast this with the days of handmade paper, when one man could make about 200 sheets of high-grade paper or 1,200 sheets of low-grade paper a day.

If one desires to test paper for household use, samples of several makes of the same general kind can be graded quite easily. They may be compared as to general appearance, weight, color, uniformity of texture, resistance to tearing, ability to withstand creasing and folding, price per pound, pounds per ream, etc.

• FROM RUBBER TREES TO RUBBER TIRES

Rubber has been known for several centuries. Before the discovery of America, the natives of tropical America utilized rubber in fashioning rough shoes, water bottles, garments, and shields from the crude gum. Early explorers soon noticed this strange material and took samples back to Europe with them. "Rubber" was the name given to this material when it was found to be useful in rubbing out pencil marks, but, for a long time, the only practical application of rubber was in the waterproofing of garments. However, the result was not very satisfactory, since the garments were soft and sticky in hot weather, hard and brittle in cold weather.

The true beginning of the rubber industry occurred in 1839.

In that year, Charles Goodyear, an American, after ten years of unsuccessful experimentation in the face of most discouraging circumstances, discovered the basic process which is fundamental to the manufacture of rubber articles. He found that heating a mixture of sulfur and rubber produced a material with new and remarkable properties quite unlike those of the crude rubber from which it was made. This process is called *vulcanization.* Goodyear's finding coupled with the later discovery that sulfur chloride could be used in vulcanizing rubber formed the foundation of the modern rubber industry. No other methods of vulcanization have since been discovered.

Rubber is a complex chemical compound that occurs in the sap or latex of certain trees, shrubs, and vines which grow abundantly in the tropics. Incisions are made in the bark of rubber trees, and receptacles properly placed catch the latex as it flows from the cuts. The rubber is coagulated into a form known as crude rubber by exposing the latex to the air, by pouring it slowly onto a rotating stick held over a smoking fire, or by treatment with weak acids, such as acetic acid—the acid that makes vinegar taste sour.

Some years ago it was foreseen that the supply of wild rubber could not long keep pace with the increasing demand, and efforts were made to cultivate rubber trees on plantations. These efforts proved successful, and today nearly all of the supply is plantation rubber. Rubber plantations are found in tropical countries, notably Brazil and the East Indies.

Waste and scrap rubber constitute another source of supply which has exerted considerable influence in keeping the price of rubber goods within reasonable limits. Processes have been devised for recovering a large per cent of the used rubber. The product is known as *reclaimed rubber.* While inferior to the original crude rubber, it can be used satisfactorily for the manufacture of many products.

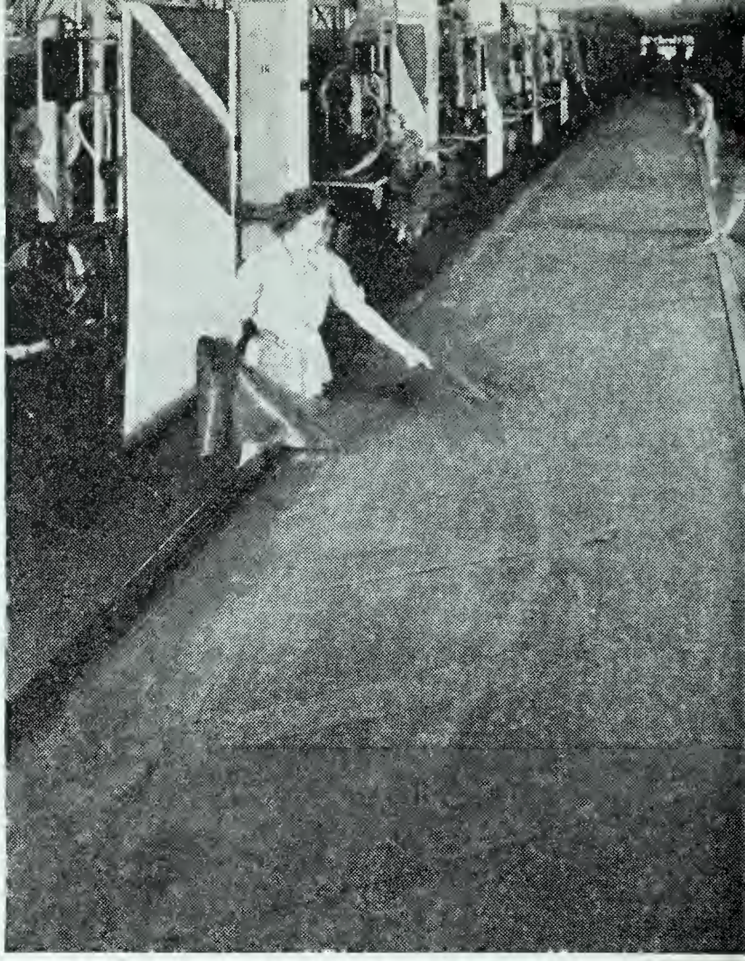
The manufacture of rubber articles involves more than simply mixing sulfur with rubber, forming the articles, and vulcanizing. Vulcanizing is still basic, but scientific research has contributed numerous refinements to the process which result in additional desirable properties in the finished product. Among the properties which make rubber so useful, these are of first rank: (1) it is elastic, flexible, and resilient; (2) it is tough and durable; (3) it is a nonconductor of electricity; (4) it is waterproof, nearly airtight, and acid-resisting.

Very few articles are made from sulfur and rubber only. In



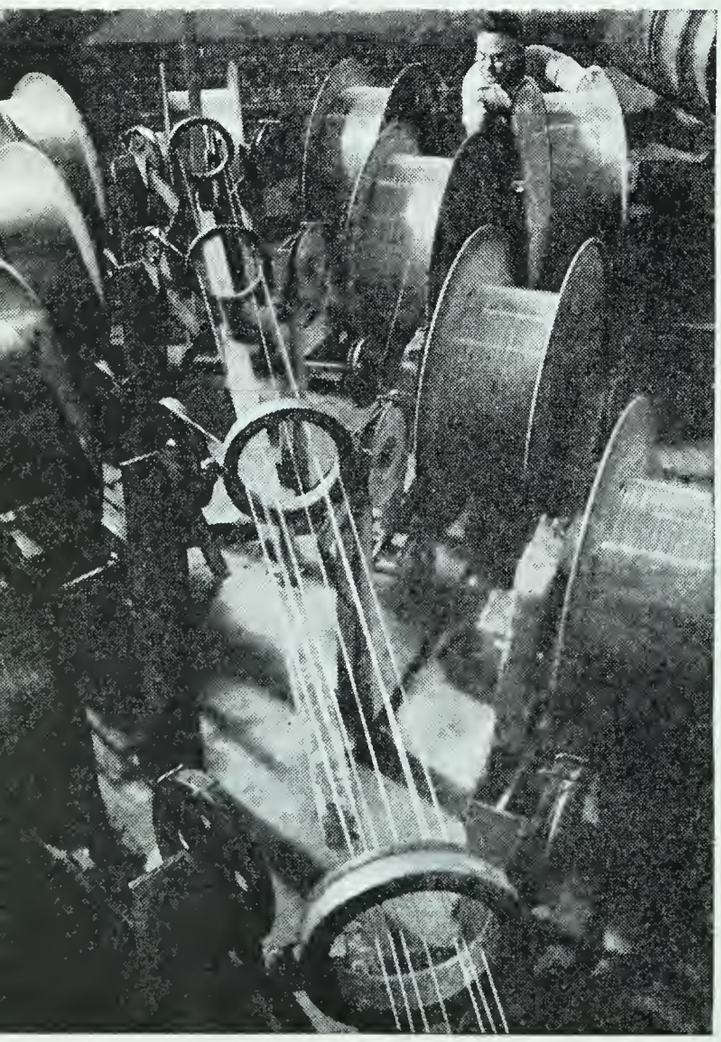
Sheets formed from crude rubber are aged before mixing with chemicals to make the rubber which is applied to the cords to make . . .

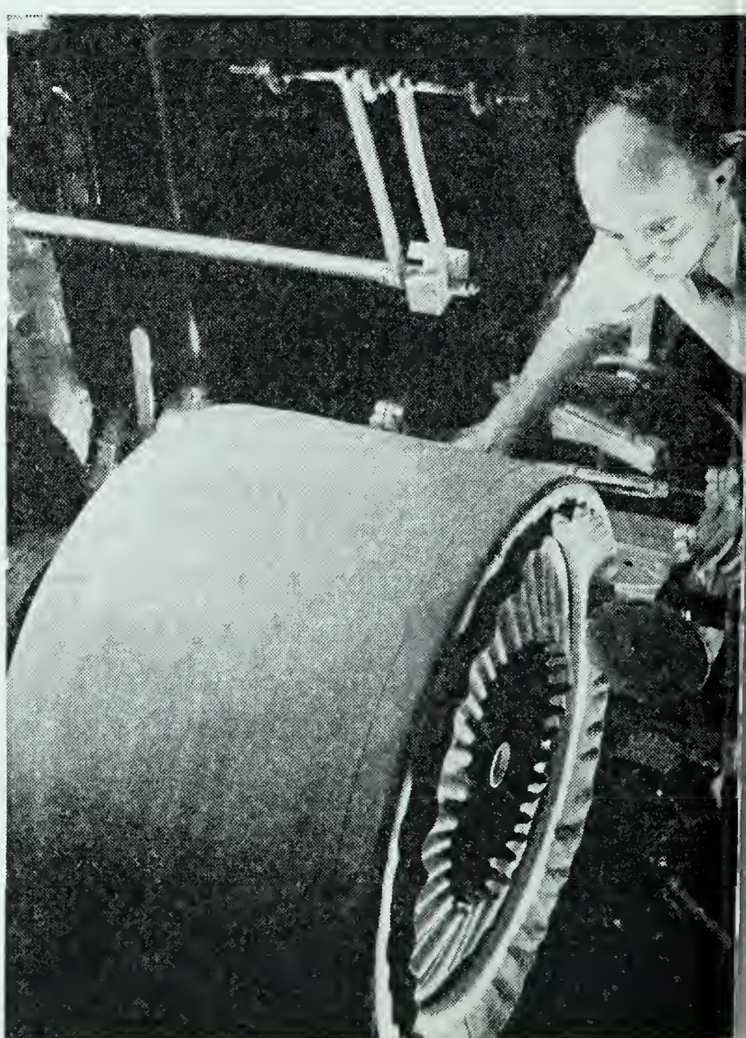
. . . the steel bead wire that is to be enclosed in the two circumferences of the tire which contact the rim, are fed to . . .

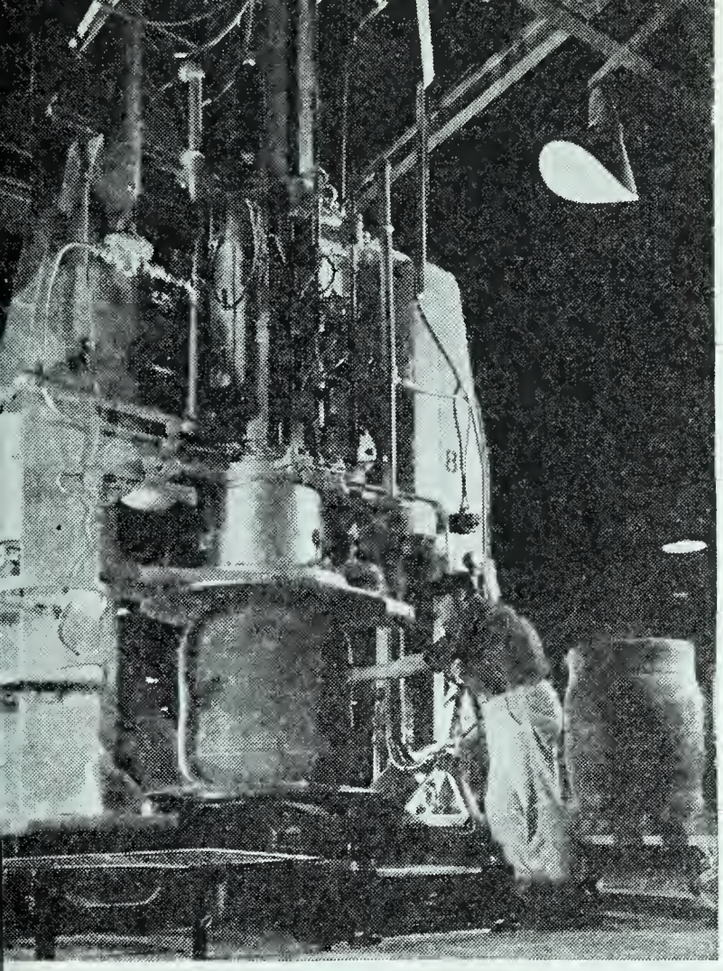


. . . the cord fabric which is cut on the bias so it will stretch when under tension in the tire. The correct size sections of the treated fabric, together with . . .

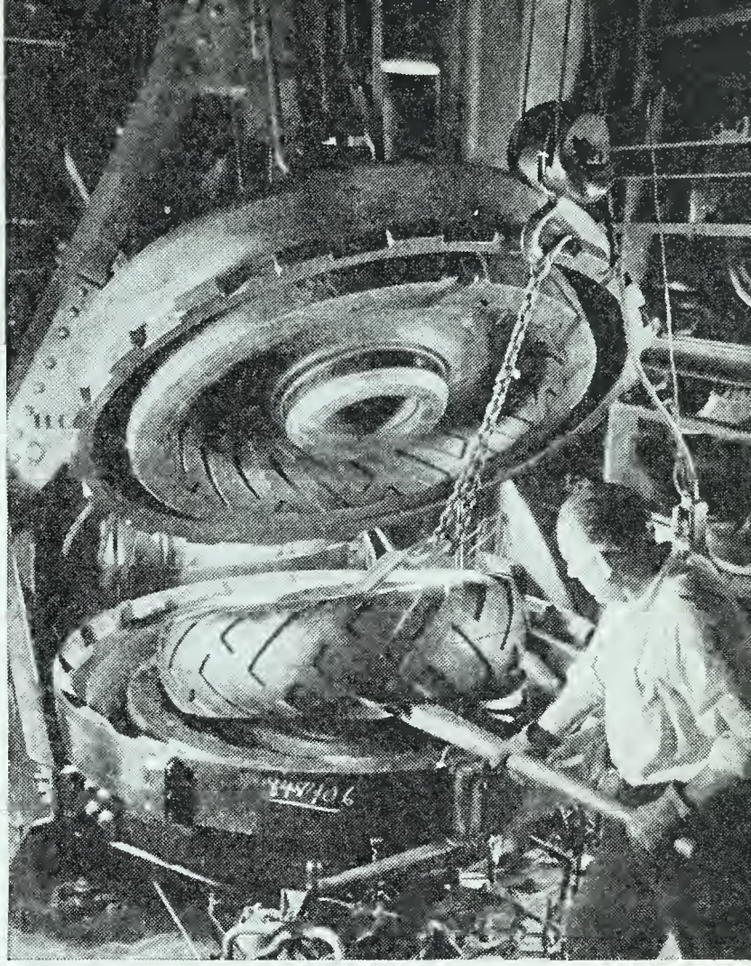
. . . the drum machine on which tires are built. The plies are built up one on top of the other, and the wire beads are stitched or rolled down. The tire then goes to . . .







. . . the shaping machine. An air bag is placed inside the tire and inflated to force the nonskid pattern of the mold into the tire during . . .



. . . the vulcanization process. Steam provides the necessary heat, and vulcanization takes place due to the sulfur and other chemicals previously added.

Photos courtesy Firestone Tire and Rubber Company

everyday practice, the rubber is "compounded"—that is, many different materials are added in regulated amounts calculated to give desired characteristics to the product. Carbon black, zinc oxide, and other so-called *fillers* are added. The technical name "fillers" is apt to be misleading—these materials are not adulterants but actually add toughness, durability, and wear-resisting properties to the finished article. Besides fillers, certain other materials called *accelerators* are added to reduce the length of time required to vulcanize the rubber.

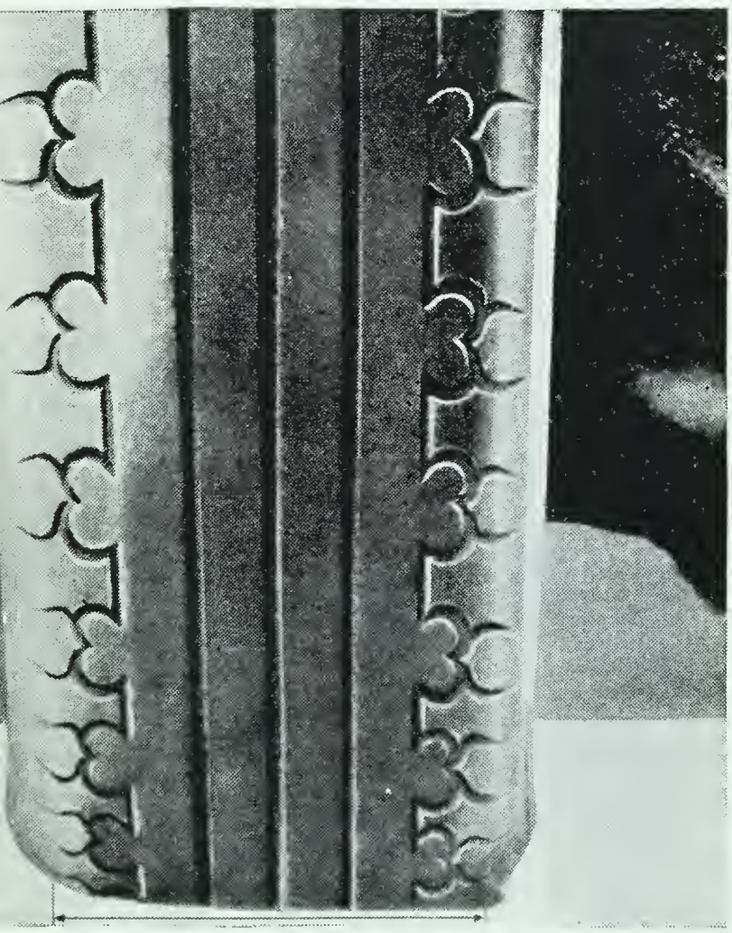
The elasticity and hardness of rubber articles are determined largely by (1) the per cent of sulfur incorporated into the rubber, (2) the temperature to which the mixture is heated, and (3) the length of time it is heated. Bringing the sulfur content to 10 per cent and heating it at about 150 degrees centigrade for a short time produces soft vulcanized rubber. Hard rubber, also called *ebonite* and *vulcanite,* is formed when the sulfur content is around 30 to 50 per cent and the vulcanizing temperature is higher. Among the familiar articles made from hard rubber are combs, brushes, telephone parts, and electrical insulators. Hard rubber is today being increasingly replaced by cheaper plastic materials.

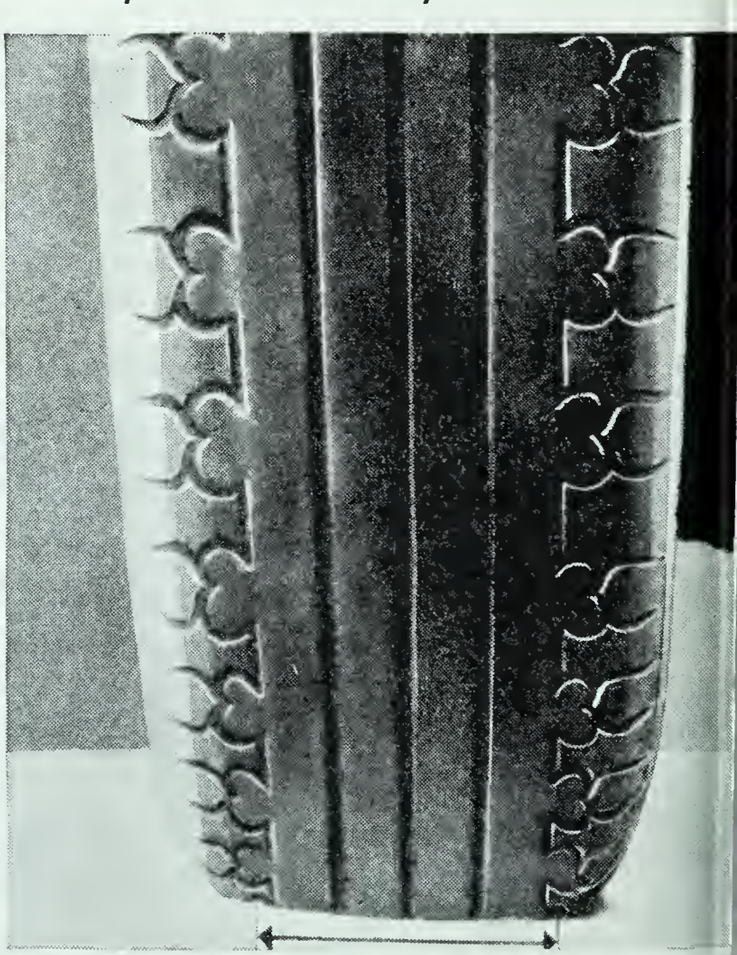


A rim-bruised tire may run miles before going flat. The outside may show no damage.



A wheel ½ inch out of line drags its tire sideways 87 feet in every mile.





A tire 30 per cent underinflated (left) gives only 74 per cent of its possible mileage.

Periodical inspection might have prevented this. When thumping warns of a flat tire, the damage is usually already done.



Photos courtesy Firestone Tire and Rubber Company

Important steps in the manufacture of automobile tires are shown in the series of illustrations. Through continued research and technical improvements, tire manufacturers have been giving the motorist increasing miles for each dollar, easier steering qualities, better cushioning, and greater resistance to punctures and blowouts. The manufacture of tires consumes the major portion of our rubber imports, but, even if this were not so, the rubber industry would still be a large one because so many useful articles are manufactured from this peculiar material.

Three agencies which speed the deterioration of rubber are heat, sunlight, and oil. Experiments have shown that articles which would last five to ten years at ordinary temperatures are destroyed in three weeks or less when maintained at a temperature of 70 degrees centigrade. This accounts for the rapid deterioration of raincoats, hot-water bags, and overshoes, which are placed on or near steam radiators to dry. Rubber bands which ordinarily last four to six years become worthless in three months if left in direct sunlight. A cool, dark place is ideal for the storage of rubber goods. Oil absorbed by rubber promotes deterioration by producing a soft spot. This is an item of particular importance in the care of automobile tires and inner tubes. Remove oil and grease as soon as possible or, better yet, see that the two do not come into contact at all.

The Rubber Manufacturers Association estimates that 99 per cent of all tire failures result directly or indirectly from underinflation. Upon striking a curb, sharp stone, or other irregular obstruction, underinflated tires "pinch," resulting in cut or broken fabric. Continued running on a flat or underinflated tire causes the cords of the side-wall fabric to separate, usually ruining the tire beyond all hope of repair. Underinflation and overinflation both cause excessive tread wear. Types of tire failure or excessive wear resulting from neglect are pictured in the illustrations. The wise motorist who wants to get the most out of his tires checks air pressure once a week or daily if driving continuously; he frequently removes all bits of glass, cinders, sharp pebbles, and the like from the tread; he shifts his tires around at intervals; he avoids quick starts and stops; and he has all repairable damage promptly attended to by a competent service man.

• TEXTILES, FABRICS, AND CLOTHING

Manufactured textiles have replaced the skins and furs worn by primitive man. As civilization developed, various textiles grad-

ually climbed to a place of high ranking among the products constructed from raw materials of the plant and animal kingdoms. Today, textiles are adapted to clothing, bedding, draperies, upholstery, floor coverings, bagging, belting, automobile tires, tents, awnings, and dozens of other uses. The manufacture of clothing uses by far the largest portion of all textiles produced, while the manufacture of bedding comes second.

Among the plant and animal fibers used in the manufacture of textiles are cotton, wool, silk, flax, and several minor ones such as jute, hemp, kapok, ramie, and sisal. Rayon and nylon are two man-made fibers which have been added to the list; even the mineral kingdom contributes one important fiber—asbestos. Fiberglas as a textile serves a number of uses.

The selection and consumption of textiles and related products present a problem of major importance to modern householders. A very large portion of the consumer's dollar goes for clothing, bedding, upholstered furniture, rugs and carpets, and the like; yet the average shopper knows very little about the really important factors that ought to be considered when making such purchases. If buying were done more intelligently, that is, on the basis of scientific facts and principles, the consumer would undoubtedly get more for his dollar.

There is no comprehensive federal law for the protection of the consumer in regard to textiles like the laws relating to foods, drugs, and cosmetics—although public demand for such laws is producing results, as evidenced by the Wool Labeling Act of 1939. Its stated purpose is "to protect producers, manufacturers, distributors, and consumers from the unrevealed presence of substitutes and mixtures in spun, woven, knitted, felted, or otherwise manufactured wool products, and for other purposes."

In addition to the Wool Labeling Act, the Trade Practice Rules, promulgated by the Federal Trade Commission for the Silk Industry, for the Hosiery Industry, for the Rayon Industry, and for the Shrinkage of Woven Cotton Yard Goods, afford protection against misrepresentation. Excellent protection is also afforded by a knowledge of the characteristics of fibers, how fibers are prepared for use, how they are woven into textiles, and how the qualities of these textiles compare. Such knowledge will help you get your money's worth when you buy.

The properties of the different textile fibers largely determine the particular characteristics and uses of fabrics made from them. The selection of fabrics, particularly for clothing and bedding,

should be made on the basis of wearing qualities, ability to transfer heat, ability to absorb and to lose moisture, and smoothness and luster. The length of the fibers and their ability to take dyes are also important characteristics. The following tabulation summarizes these characteristics of the "big four" of the fiber world.

Heat conductivity (depends on air content—the greater the air content, the poorer the conductivity)	Linen conducts heat most rapidly. Cotton conducts heat less rapidly than linen, but it is a better conductor than silk and wool. Silk and wool are both poor conductors of heat, wool probably being less conductive.
Tensile strength (the amount of stress the fiber can withstand before breaking)	Raw silk is strongest and wears best. Pure linen is next and ranks first in retaining strength after long periods of storing. Cotton is next to linen, but is less affected by bleaching during preparation. Wool fibers have the least strength.
Loss and gain of moisture	Linen absorbs moisture most rapidly and dries out most rapidly. Raw silk absorbs and holds large quantities of moisture; most silk fabrics on the market neither absorb nor lose moisture rapidly. Cotton absorbs and loses moisture slowly. Wool gains and loses moisture still more slowly.
Luster (depends on fiber structure and how it reflects light)	Silk is the smoothest and most highly lustrous of the natural fibers. Linen is not so lustrous as silk, but more so than cotton. Cotton is dull and lusterless. Wool is lacking in luster.

Rayon closely resembles cotton in most of the properties listed above but is even smoother and more lustrous than silk. In fact, when rayon was first put on the market, it was too shiny and lustrous. Women objected, so chemists had to find an agent to add during manufacturing processes which would deluster the rayon.

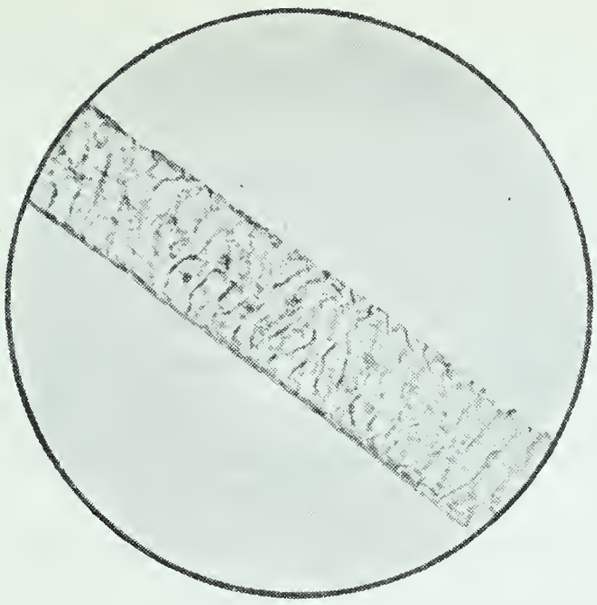
Nylon is also very smooth, and, even though nearly as fine as a spider's web, it has great tensile strength.

To see how the properties and uses of fabrics are related, let us consider clothing. One of the important functions of clothing is to help regulate body temperature. The source of body heat is the food we eat. Excess heat is lost from the body by radiation, by conduction, and by the cooling effect of evaporation. Clothing generally aids in maintaining body comfort by regulating these processes. Linen garments are particularly desirable for wear during hot weather and in tropical climates, because this fabric conducts heat readily. In addition, linen absorbs perspiration and evaporates it rapidly, thus producing a cooling effect; it is easily penetrated by air, thus giving circulation close to the body. Wool, on the other hand, is generally accepted as the best material for winter wear. This is due to the poor heat conductivity resulting from the large amount of air entrapped by the fibers. Cotton garments are not so satisfactory as linen for summer wear but are preferable to silk or woolen ones of comparable weight.

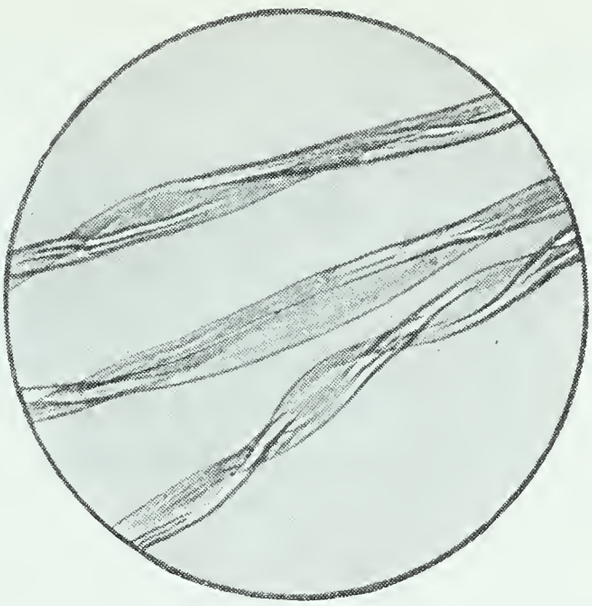
There are many steps and several by-products in preparing fibers for use. *Cotton.* After being picked, cotton is taken to the ginning mill where the seeds are removed. The *ginned* cotton is later cleaned, and the fibers are straightened; then they are twisted together and spun into thread. Cotton fibers are the shortest of the "big four," but because of their flat, twisted nature, they can still be spun into strong thread.

Cotton seeds once constituted a disposal problem, but now they give rise to several valuable products. First, the short cotton fibers are removed. These are called "linters" and find extensive use in making cotton batting and wadding, cheesecloth, rayon, cellophane, and certain plastic materials (see p. 458). After removal of the linters, the cotton seeds are pressed, giving cottonseed oil and oil cake, or meal. Cottonseed oil is widely used as a salad oil, and large quantities are converted into substitutes for lard. The oil is changed to a solid fat by *hydrogenation,* a chemical process which causes hydrogen and the oil to unite. Soap can also be made from cottonseed oil. The oil cake is used for cattle feed and as a fertilizer.

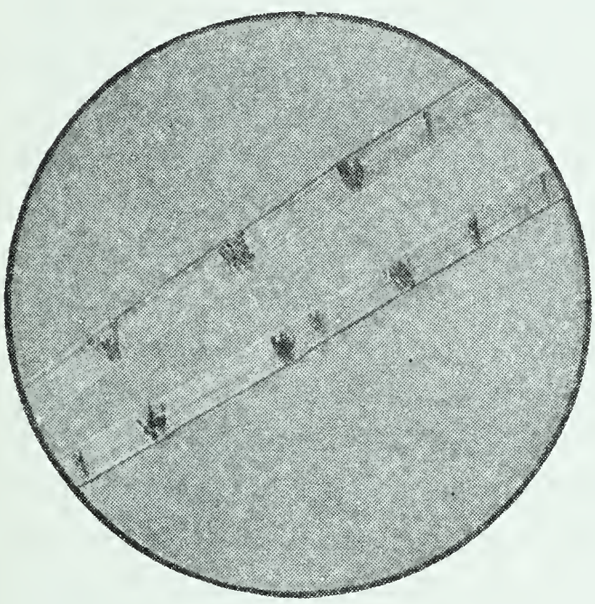
Linen. Linen fibers are made up of many hollow, cylindrical cells cemented together end to end. They are obtained from the inner bark of the flax plant, where they serve to conduct fluids from one part of the plant to another. The stems of flax plants grown expressly for their fibers are subjected to a process known



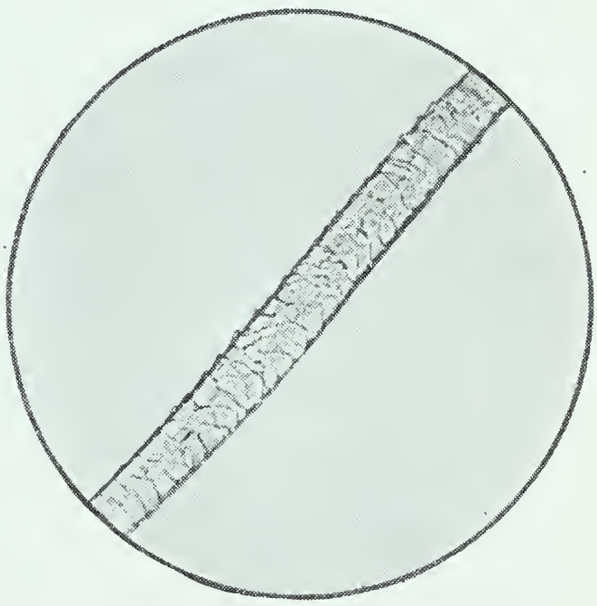
Coarse Wool



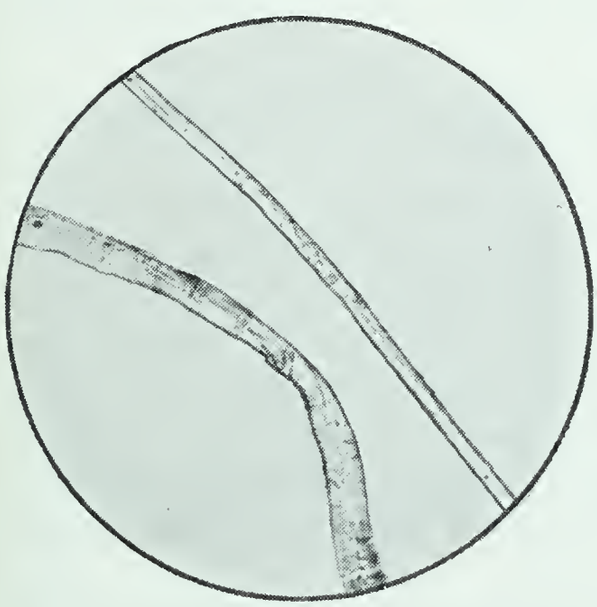
Absorbent Cotton



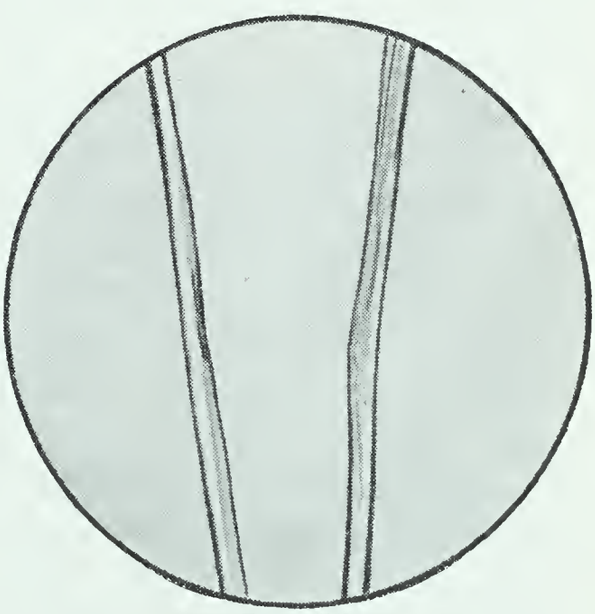
Flax Fibers



Wool



Linen



Raw Silk

Courtesy Federal Security Agency, Food and Drug Administration

These photomicrographs of textile fibers magnify the fibers to three hundred times their natural size.

as *retting.* This is a fermentation process which softens the stems by rotting, and loosens the desired fibers. The fibers are removed, cleaned, straightened, and spun into yarn.

Wool. Several animals provide us with various kinds of wool. Mohair is the wool of the Angora goat; alpaca comes from the llama; cashmere is the fleece of a Tibetan goat; camel's-hair wool comes from African and Asiatic camels. Ordinary wool comes from the domestic sheep.

To prepare the wool for use, it is first thoroughly washed and cleaned. The wash water is saved, for from it is obtained the by-product *lanolin,* a greaselike substance used extensively in making cold creams. The clean wool is rinsed and dried, a correct amount of vegetable oil is added to grease and soften the fibers again, and it is then spun into yarn. Wool fibers are springy and covered with scales, the latter causing them to cling firmly together when spun.

Wool which has not previously been manufactured into a finished product is known as *new* or *virgin* wool. There is also *reprocessed* wool. This is wool that has been woven once, then unwoven, then woven again without ever having been worn or used. To all intents and purposes it is new wool. It may be inferior to a comparable grade of new wool, but may still be more serviceable than a poor quality of new wool. The waste fibers and small pieces of fabric left over in the manufacture of clothing are reclaimed and made into "shoddy," as are cast-off and worn-out clothing. These materials are unwoven, and the wool is cleansed, treated, and dyed before it is used again. This product is called *reused* wool.

Silk. There are several varieties of silk, but the best grade comes from the silkworm which feeds on mulberry leaves. The silk fiber is a long, continuous filament spun as a protective covering for the larva as it changes into the moth. Each fiber consists of two filaments cemented together by a gummed coating. In preparing silk for the market, the cocoons are placed for a while into pans of hot water to soften the gum. The fibers are then carefully wound onto reels to be made later into thread and yarn. There is considerable reduction in the weight of silk when the gum is removed, and this is generally made up by "weighting" the silk with certain chemicals, particularly tin compounds.

Nearly all textiles are bleached at one stage or another in their preparation for use. The oldest method of bleaching, still practiced to a considerable extent on both cotton and linen, is grass bleaching. The finest linens of Ireland, Belgium, and other fa-

mous sources are still bleached in this fashion in spite of the development of more modern chemical methods. The procedure consists of moistening the linen cloth or articles and spreading them out on the grass for a period of several weeks. Sunlight and oxygen from the air or freshly liberated from the grass by photosynthesis bleach the linens to a pure white color. This method is most time consuming, but it is the least injurious to the fabrics. Grass bleaching is a process in which oxygen unites with coloring matter to form a colorless compound:

$$\text{coloring matter} + \text{oxygen} \rightarrow \text{colorless compound}$$

Certain chemical bleaches have been found to accomplish this oxidation in much less time and are therefore widely used to speed up production. Commercially, the most important of these are chlorine, hydrogen peroxide, and bleaching powder, also called chlorinated lime or chloride of lime.

Bleaching by chlorine or chloride of lime is an oxidation process, even though we speak of chlorine as the bleaching agent. To be effective, chlorine must act on *moist* cloth; it has little or no bleaching action on dry materials. The explanation lies in the fact that chlorine slowly reacts with water thusly:

$$\underset{Cl_2}{\text{chlorine}} + \underset{H_2O}{\text{water}} \rightarrow \underset{HCl}{\text{hydrochloric acid}} + \underset{HClO}{\text{hypochlorous acid}}$$

The hypochlorous acid then acts on the coloring matter, transferring oxygen to it:

$$\text{colored substance} + \underset{HClO}{\text{hypochlorous acid}} \rightarrow \text{colorless substance} + \underset{HCl}{\text{hydrochloric acid}}$$

These explanations show that bleaching with chlorine produces hydrochloric acid in the wet fabric. Acid and excess chlorine are undesirable, because they lead to weakening and early failure of the fibers. Both of these chemicals are removed by an antichlor solution and by thorough rinsing.

Chlorine destroys tissues, fibers, and similar materials of animal origin. It cannot be used safely to bleach silk, wool, hair, feathers, ivory, and the like. These materials are sometimes bleached with hydrogen peroxide, a familiar household chemical. It is harmless in its action and will bleach most materials. Hydrogen peroxide is unstable and gives off oxygen readily when shaken or brought into contact with finely divided material or rough sur-

faces. The release of oxygen is what causes the bubbles and foaming when hydrogen peroxide is put on a cut or used to clean the teeth. The only residue from this action is water:

$$\underset{2H_2O_2}{\text{hydrogen peroxide}} \rightarrow \underset{2H_2O}{\text{water}} + \underset{O_2}{\text{oxygen}}$$

Another bleaching agent frequently used on animal materials is sulfur dioxide, the gas produced when sulfur burns. Like chlorine, sulfur dioxide is an effective bleach only in the presence of water, with which it unites chemically according to the equation:

$$\underset{SO_2}{\text{sulfur dioxide}} + \underset{H_2O}{\text{water}} \rightarrow \underset{H_2SO_3}{\text{sulfurous acid}}$$

Sulfurous acid does the bleaching by *extracting* oxygen from the colored substance in the material being bleached:

$$\text{colored substance} + \underset{H_2SO_3}{\text{sulfurous acid}} \rightarrow \text{colorless substance} + \underset{H_2SO_4}{\text{sulfuric acid}}$$

From this equation we can conclude that bleaching with sulfur dioxide (1) is the opposite of oxidation—that is, reduction; (2) produces sulfuric acid in the material being bleached, so that thorough rinsing is necessary; (3) is only temporary, since the bleached materials may take on oxygen from the air and thus regain their color. This last fact explains why silk, ivory, straw, and similar materials usually turn yellow with age.

In conclusion, we may point out the generalization that bleaching may be either an oxidation process or a reduction process.

Textiles are treated in many ways to enhance their appearance and improve their quality. Cotton is made to resemble silk in appearance by *mercerizing*. In this process, cotton cloth or yarn is tightly stretched on a frame and is immersed into a solution of sodium hydroxide for a suitable length of time. As a result, the cotton fibers become thinner, smoother, much less twisted, and more tubular, all of which gives greatly increased luster. In addition, the fibers are strengthened and the fabric takes dyes much more readily and completely. The sale of mercerized cotton as silk is a violation of the Trade Practice Rules for the Silk Industry.

Sizing, dressing, and weighting materials are generally added to textiles for legitimate reasons, and if not excessively used, they are not objectionable. Starch, dextrin, glue, casein, and other adhesives are frequently added to cotton and linen to improve the fin-

ish and increase the firmness of the woven fabric. Soaps, or oils and fats, and certain chemicals may be used to soften the fibers and keep them moist during spinning and weaving. Clay and similar chemicals or minerals may be added to increase the weight of the fabric. The effects of many of these treatments are permanent, but laundering may reduce the life of some.

Textiles are sometimes treated to render them waterproof or dustproof. Insoluble chemicals may be incorporated into the fabric thus closing the pores, or the fabric may be given a coating of oils, fats, waxes, or rubber.

By a process known as *Sanforizing,* the tendency of cottons and linens to shrink when washed has been overcome nearly 100 per cent. After testing a sample to determine how much it shrinks when washed, an entire bolt of the fabric is firmly attached to a heavy woolen blanket and fed into a machine. Here water and steam play upon the cloth. The blanket is under controlled tension and, as the tension is gradually released, the attached cloth shrinks uniformly to the predetermined width and length. The cloth will shrink very little, if at all, during further washings. Garments labeled "preshrunk" have not necessarily been treated in this fashion. Trade Practice Rules for the Shrinkage of Woven Cotton Goods provide specific requirements regarding labeling as to shrinkage.

Modern dyestuffs give us beautiful colors that "all the king's money" could not buy in days past. These dyes come from many sources, such as plants, animals, minerals, and coal tar, and many are manufactured from chemicals.

Indigo, one of the earliest dyes used, was formerly obtained 100 per cent from the juice of a certain plant grown in tropical regions, such as India, Java, and Guatemala. Although natural indigo is still produced to some extent, synthetic indigo is now made largely from naphthaline, the chemical commonly used in moth balls, which in turn comes from coal tar.

Alizarin is a purple-red dye formerly obtained by fermenting the root of madder, a plant native to India, but now manufactured almost totally from another coal-tar product, anthracene.

Tyrian purple was the costliest of all ancient dyes. It came from the bodies of certain small snails which inhabit the Mediterranean Sea. When pursued by larger animals, these snails eject this coloring matter to color the water and aid their escape. The dye was very costly to obtain in any large amount and has long been associated with kings, hence the expression "the royal purple." Syn-

thetic substitutes are now available, likewise made from coal-tar.

Cochineal is a red dye obtained by soaking in water the dried bodies of female insects of a certain kind found in Mexico. Scarlet, crimson, and orange colors are produced. It is said that seventy thousand of these insects are needed to produce one pound of dye. Coal-tar dyes are rapidly displacing cochineal reds and oranges.

From the preceding paragraphs, we see that the coal-tar dye industry is apparently a very important one. It is inspiring to learn that this great industry was started by the findings of an enthusiastic, ambitious, eighteen-year-old boy—William Henry Perkin, a student at the Royal College of Chemistry in London. In 1856 he tried to prepare quinine artificially from aniline, a coal-tar product. His experiment failed insofar as preparing quinine was concerned, but the product proved to be a durable and beautiful purple dye. It was called *mauve*.

The coal-tar dye industry developed rapidly, particularly in Germany. By the year 1900, about five hundred dyes were known; today there are more than five thousand. The United States imported all of its dyes from Germany up to the time of our entrance into the World War in 1917. At that time, American chemists were called upon to develop the industry, and the success of their efforts is indicated by the fact that today we make 95 per cent or more of the dyes we use and even export more than we import.

Other natural dyes still used today include logwood, made by boiling chips of the heartwood of the campeachy tree found in Central America, and many mineral colors, such as iron buff, Prussian blue, chrome yellow, and others. In colonial days, women made their own iron buff in an interesting way. They partially filled a barrel with water and vinegar and threw into it old nails and other scrap iron, which was acted upon by the acid of the vinegar. They would saturate their homespun in the resulting solution and then rinse the cloth in water which had run through wood ashes. The alkali of this solution neutralized the acid of the vinegar solution and also changed the iron compound so that, upon exposure to air, a buff color developed.

Most dyeing jobs are tasks for experts, but many dyes have been prepared for home use. Directions for use come with each package, and, if followed carefully, good results are usually obtained. Since dyes behave differently towards various kinds of fibers, it is essential to know what kind of fabric you wish to dye and to get the right dye for it. The fabric must be thoroughly

washed and cleaned; if new, all sizing and dressing should be removed by boiling in water containing washing soda or plenty of soap. The dye bath should be of the proper concentration and should be made with soft water, since the minerals of hard water may alter the color produced by the dye. For the same reason, porcelain or enameled vessels are preferable to metal ones. Stir the material in the boiling dye bath so the dye comes into contact with all parts of it. Finally, thoroughly rinse the material after dyeing it the proper length of time. This removes excess dye and insures the quality of the finished product. Very few dyes will adhere well to fibers, particularly those of vegetable origin, without the help of another substance called the *mordant*. Different colors can be obtained from the same dye by using different mordants with it.

The quality and durability of a fabric depend considerably on the way it is woven and finished. This is particularly true of wool fabrics. There are two classes of wool fabrics: namely, woolens and worsteds. The chief difference is that in woolen yarns the fibers are crisscrossed, intermixed, and matted in all directions, while in worsted yarns the fibers are combed to lie parallel to one another before they are spun into yarn. Worsted yarns are even, smooth, and fairly strong and are made into the most durable of all wool fabrics. Serge and gabardine are examples of worsted fabrics. They are hard and firm but tend to get shiny with wear. Woolen yarns are fuzzy in appearance, soft, and elastic but not as strong as worsteds. Examples of wool fabrics are tweed, cheviot, flannel, and woolen broadcloth.

Wool fabrics gain most of their beauty from their finish, the weave being almost completely concealed by felting and napping. Worsteds, on the other hand, are finished clean, and the weave is very apparent. Close, firm weaves made with evenly twisted yarns of the same number and quality in the warp (lengthwise threads) and in the filling (crosswise threads) result in the most serviceable fabrics. Style, however, also demands intricate novelty weaves in which serviceability is often sacrificed and the cost increased.

The following tabulation gives the nature and characteristics of the more common weaves.

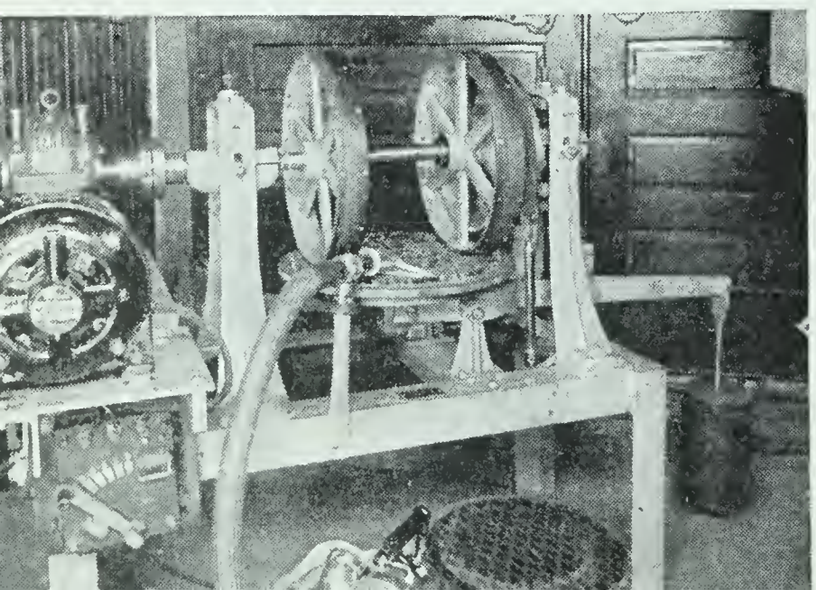
Plain weave	One filling thread over and under one warp thread. A heavier warp than filling thread gives a corded effect, as in poplin. Genuine homespun, alpaca, voile crepe, and some flannels, tweeds, and broadcloths are examples.

Basket weave	Two or more filling threads over and under two or more warp threads. Durable if firmly woven.
Twill weave	Warp threads pass under one and over two or more filling threads, giving a diagonal effect. May be regular and continuous, as in serge and gabardine, or broken, as in herringbones and figured patterns.
Double weave	Double layer of warp and single set of filling threads, or two complete sets of warp and filling held together by a fifth yarn. Mackinaw and heavy polo cloth are examples.
Padded weave	Made by drawing the under yarns tighter than the surface yarns. Piqué and Bedford cord.
Crepe weave	Made by combining yarns under different tensions, or combining right-hand twisted and left-hand twisted yarns.
Pile weave	Looped threads on surface as terry cloth or a clipped finish like plush.
Novelty weave	Made by use of special yarns; by combining two or more of above weaves; by mixing different kinds of yarn as silk and rayon with wool; by using worsted warp and woolen filling; and other techniques.

The better informed you are about consumer goods, the more likely you are to recognize the "good buys." There are many sources from which the consumer can obtain information—government pamphlets, textbooks, general reference books, booklets published by private organizations, consumer clubs, and certain radio programs, such as the National Farm and Home Hour. It is always necessary to consider carefully the trustworthiness of a source, since a great deal of money is spent in advertising inferior products. There is no royal road to consumer wisdom—it takes careful investigation, much of which is being done for us these days by reliable agencies. Intelligent salespeople prefer to deal with informed and wide-awake purchasers; on the other hand, the job of modern salespeople is more than taking your money

This machine gives a carpet the same kind of hard wear that lots of walking on it does.

Courtesy National Bureau of Standards



and wrapping up your purchase. In general it is wise to buy from those who are thoroughly acquainted with their goods and willing to educate the prospective buyer as well as to "sell" him.

• MISCELLANEOUS PRODUCTS

Many different kinds of animals contribute to our supply of leather. The following tabulation gives the sources of most of our leather, together with a brief description of the outstanding properties of each kind.

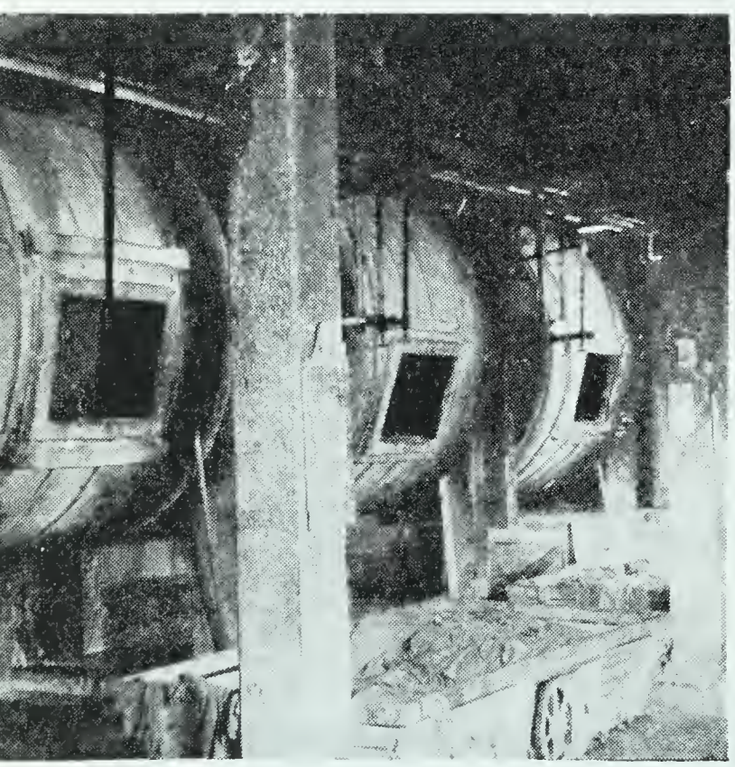
Calfskin	Comes from young cattle. Is firm, resists scuffing, and is serviceable if of good quality. Much used for women's and children's shoes. Much so-called "calfskin" is really made from the split hides of older animals.
Cattle hide	Heavier than calfskin, coarser grained, but durable; the most widely used leather for inexpensive shoes.
Kidskin (goat leather)	Lighter than calfskin leather, but very strong. Is flexible, porous, fine grained, and does not crack; scuffs rather easily. Leading kind of leather for women's shoes. Cheap so-called kid shoes are probably sheepskin, which is coarser grained, stretches, scuffs, and tears more easily. Special tanning and finishing of kid produces genuine Morocco leather.
Horse hide	Tough, stiff, and long wearing. Not used much for shoes, but for heavy leathers as in bags, belting, harness, and saddles.
Elk and buckskin	Genuine buckskin comes from elk or deer. Is flexible and porous; buckskin shoes are cool for summer wear. Split cattle hide is sometimes sold as buckskin. "Elk" leather is a specially tanned and finished cattle hide. Fine, light-weight elk leather is made from heavy calfskins; is soft and sturdy.
Kangaroo	Soft, fine grained, resists scuffing. Strongest leather known for given weight and thickness. Expensive.

In addition to the above sources of leather, considerable amounts are also produced from the skins of snakes, alligators, and crocodiles, sharks, seals, walruses, pigs, dogs, ostriches, and even fish. When we consider the many uses for leather—shoes, gloves, purses, luggage, saddles, belting, helmets, puttees, and dozens of other articles—we see why so many kinds of leather have been developed.



Courtesy Armour Leather Company

This machine removes the hair after it has been loosened by soaking the hides in lime solution.

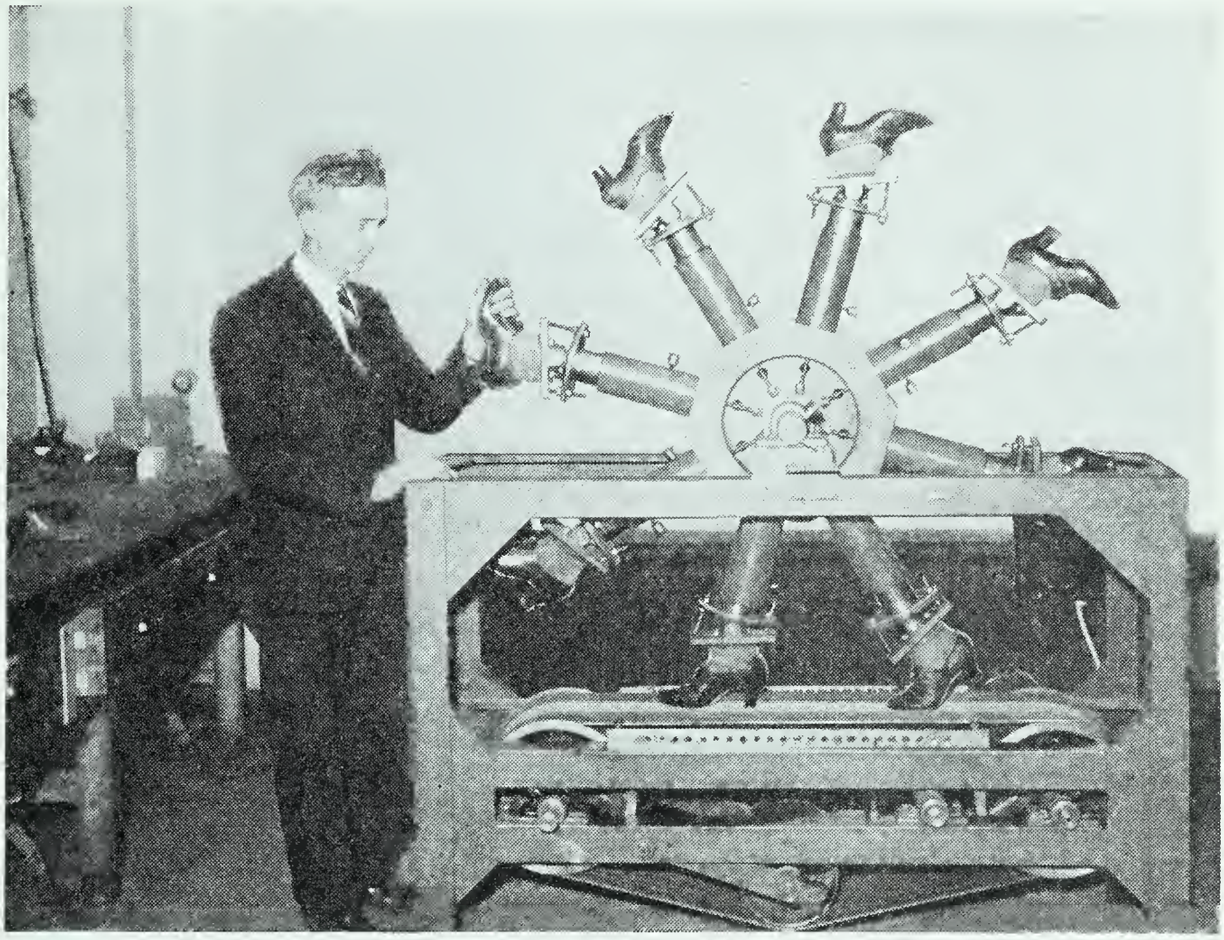


Courtesy Armour Leather Company

After being treated in solutions which neutralize the lime and open the pores so that the tanning liquid will be absorbed, the hides are placed in these revolving drums for the actual tanning.

Hides and skins used as leather must be tanned. Before the tanning process, all fatty and meaty material is removed from the pelts. This with all trimmings is used to make gelatin, glue, and fertilizer or to provide grease for soapmaking. The hair is then removed from the pelts by chemical treatment with lime-water and by the shearing action of a revolving roller equipped with several sets of blades. The hair is not wasted but is used to make felt, to serve as the binder in mortar and plaster, and to supply the stuffing material for mattresses and upholstery. Finally, the raw skins are ready for tanning operations which change them into leather.

Leather is tanned by two entirely different processes—vegetable tanning and chrome tanning. In vegetable tanning, the skins are suspended in a tank containing a water solution of selected woods, barks, and leaves which provide tannin. The first solution is weakest, and the skins are transferred day by day to more concentrated solutions until they are completely tanned. This usually takes about ten days. During this time, tannin chemically combines with certain substances in the skin and a new product is formed —leather.



Courtesy National Bureau of Standards

This machine is for artificially "walking" shoes to determine how long they would last in actual wear.

In chrome tanning, the prepared skins are first soaked in a solution of sulfuric acid and common salt; then they are treated with a solution containing a chromium compound. This compound soaks into the skin and causes the chemical changes which produce leather.

Chrome-tanned leather is generally conceded to be less desirable than vegetable-tanned leather for shoe manufacture, especially for the soles. Vegetable tanning leaves the pores of the leather unclogged, and shoes so tanned allow the feet to "breathe." Leather made in this way undergoes little change with changing moisture content of the air, whereas shoes of chrome-tanned leather become too large in damp weather and too tight in dry weather. Very little leather for shoe soles is chrome tanned, but about 90 per cent of all the leather for uppers is made by this process.

Tanned leather is oil treated to make it soft and pliable; this treatment also increases its strength. If colored leather is desired, the tanned skins are put into revolving drums, and dye solutions are poured over them through a hollow axle.

The many special finishes given to leather require highly skilled artisans and provide us with leathers of beauty and utility. Examples of such finishes are suede, embossed, smooth, Scotch grain, and patent leather. Most of these are obtained by mechanical treatment; patent leather, however, is produced by coating tightly stretched leather with varnishlike materials or linseed oil.

The consumer problem of knowing the origin and hence the probable wearing qualities of furs is a complicated one. This is because so many methods have been developed for giving cheap or low-grade pelts the appearance of more expensive varieties and grades. By skillful dyeing, bleaching, blending, or other treatment, almost magical results are obtained in fur manufacture. Happily, there is a growing tendency among reputable dealers to attach labels to fur garments giving exact information as to origin, special treatment, serviceability, and recommended care.

In general, furs are prepared for the market much in the same manner as leather. All adhering flesh and fat are scraped from the pelts, after which they are tanned. Various methods give different kinds of underneath leather. Oil is then rubbed into the flesh side of the pelt. Finally, they are "tumbled" in large rotating drums containing fine sawdust, to remove excess oil and grease and to give the fur luster.

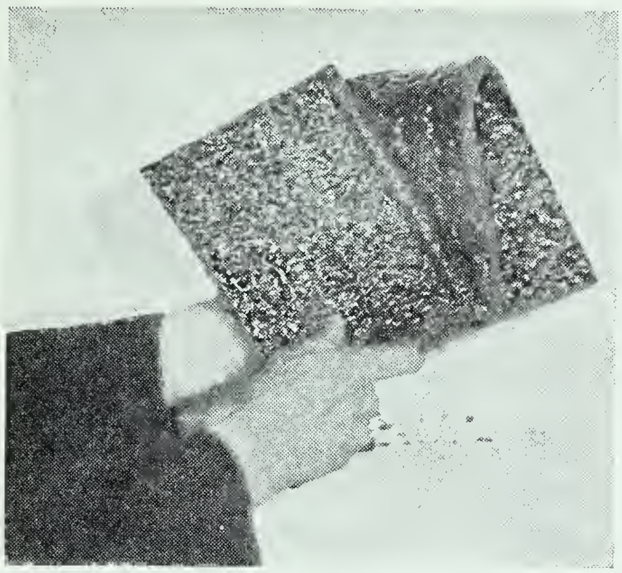
Perhaps the best advice to the prospective purchaser of furs is "select your furrier very carefully." It is best to deal with a merchant who has a well-established reputation for fair dealing. Beware of the "doorbell" salesman and the merchant who rents a vacant store and puts on a big sale of "fur bargains—direct from wholesaler to buyer."

Rules have been established for the naming of furs; reputable dealers adhere to them, and prospective buyers should insist upon their application to the furs under consideration. Here are the rules in brief:

Rule 1. In order to describe a fur, in every case the correct name of the fur must be the last word of the description, and if any dye or blend is used simulating another fur, the word "dyed" or "blended" must be inserted between the name signifying the fur that is simulated and the true name of the fur, as: "Seal-dyed Muskrat" or "Mink-dyed Marmot."

Rule 2. All furs shaded, blended, tipped, dyed, or pointed, must be described as such, as: "Black-dyed Fox" or "Pointed Fox."

Rule 3. Where the name of any country or section is used, it



Courtesy Armstrong Cork Company

A first step in linoleum manufacture is to promote the union of linseed oil and oxygen from the air to form the flexible, rubbery mass.

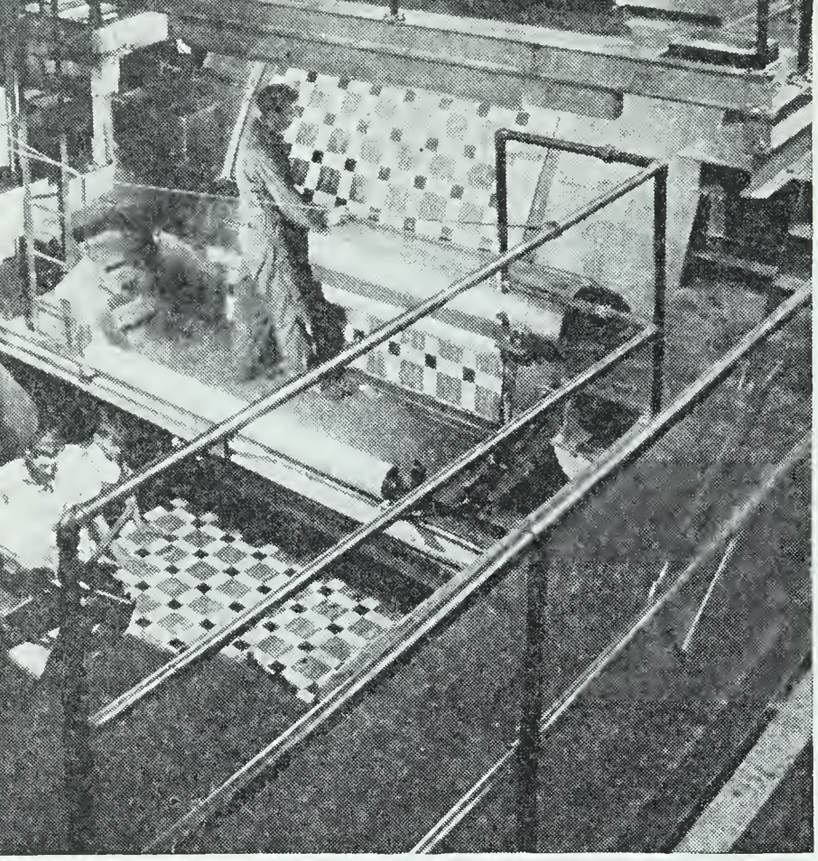
shall be the actual country of the origin of the fur, as: "American Opossum."

Rule 4. Where goods are sold under a registered trade-mark, that trade-mark should not, by intent or otherwise, be capable of misinterpretation by the public. In case of trade-marks heretofore established in common use, the advertisers should invariably indicate by suitable descriptive matter in addition to the trade-mark just what the fur is or, better, the trade-mark should be modified so as to include the descriptive matter. This refers to such trade-names for rabbit as "Beaverette" and "Sealine."

Oilcloth and linoleum are prepared by oxidation. The chief ingredients of manufacture in both these materials is linseed oil, which is obtained from flaxseed. Linseed oil is a drying oil; that is, it unites with oxygen from the air to form a kind of gum. Oilcloth consists of a fabric coated with a number of layers of pigmented linseed oil which has dried by oxidation. The final coat may be decorated with a printed design.

In making linoleum, linseed oil is sprayed upon long sheets of cloth hung in a warm room. After one layer of oil hardens by oxidation, another layer is added by spraying. This is repeated until the coating is an inch or more thick. The oxidized oil is then removed from the cloth backing; it is shredded, mixed with rosin, and heated until it almost melts. The result is a tough, rubberlike mass. Cork dust, fillers, and coloring matter are thoroughly incorporated into this cement of oil and rosin, producing linoleum dough. While warm and soft, this final mixture is spread onto canvas or burlap and passed between rollers, which unite it firmly with the fabric. The resulting linoleum is ready for use after it has seasoned for several weeks. Seasoning is highly important in producing good-quality linoleum.

Inlaid linoleum has its designs formed by solid colors which run through to the burlap backing, and the pattern lasts as long as the



Courtesy Armstrong Cork Company

This machine takes linoleum mix, forms it into a blanket, cuts out pieces, fits them together, and presses them firmly and evenly onto a burlap backing. The men are inspecting the product, inlaid linoleum.

linoleum lasts. Cheaper, printed linoleum is plain linoleum with a pattern stamped on in heavy paint. When the paint wears away, the design is lost, and the appearance is marred.

In spite of the development of substitutes, wood, the chief product of the forest, still ranks very high, if not first, in importance among construction materials. There are many reasons why this is so. In the first place, wood has many advantageous properties. It is light in weight, yet strong enough to withstand the ordinary forces which tend to pull it apart or crush it. It is soft enough to be easily cut and worked to desired sizes and shapes. It is easily joined together and fabricated. It is resilient, or springy, making it desirable for floors and steps. It is a poor conductor of heat.

Secondly, the natural appearance and the grain of wood make it a very attractive material for many uses. A cherry table, a black-walnut desk, mahogany furniture, oak floors, an interior finished with knotty pine—all are highly prized possessions because of the character of the wood composing them. The grain of wood results partly from the nature of tree growth and partly from the way the log is sawed and the lumber cut.

Wood has its drawbacks and limitations, however. It burns readily and thus constitutes a fire hazard. It decays rapidly when damp and exposed to air. Termites also attack and destroy it. The strength of wood limits its use to small and medium-sized structures.

There are many varieties of wood, and they differ widely in their properties. It is important to use the correct wood for every purpose. An experienced builder, carpenter, or architect can help one make the proper selection. Lumber is graded and classified according to definite standards of the industry.

At the mill, logs are ripped into slabs and sawed into boards.

In recent years, much experimentation has been done on the problem of utilizing the waste bark, chips, shavings, and sawdust particularly in the United States Forest Products Laboratories, Madison, Wisconsin. They have achieved considerable success in producing resins from lignin, the material which binds cellulose fibers together in wood. One large lumber company has developed an ingenious process of utilizing waste sawdust. They force it into a tubular mold under great pressure, the heat of compression causing it to fuse somewhat. When cool, it is ejected from the mold in the form of a log-shaped chunk and is an excellent fireplace fuel. Chemicals are sometimes mixed with the sawdust to produce brilliantly colored flames when the log burns.

An important step in making good lumber is to dry it properly. Formerly, new lumber was loosely stacked out-of-doors and allowed to stand several weeks to dry. Today it is nearly all kiln-dried to the correct degree of moisture content, for this method is quicker and makes possible more accurate control.

Exercises for Problem Study and Review

1. Explain the meaning and relative value of the following: mechanical pulp, chemical pulp, rag pulp.
2. What is "sized paper"?
3. Why is rubber vulcanized? How is it done? What are fillers? Accelerators?
4. Formulate a list of rules which you can recommend for the proper care of rubber articles including rubber tires.
5. What do you think is the best way to become a more efficient buyer and consumer of clothing? Choose some article of clothing and illustrate your plan.
6. What uses are made of cotton seeds, cotton linters, and cotton-seed oil?
7. What is the source of linen? Wool? Silk? How are they bleached and otherwise processed?
8. What is the chemical explanation of the bleaching action of chlorine? Hydrogen peroxide? Sulfur dioxide? Why do manufacturers of textiles use a variety of bleaching agents?
9. What is mercerizing? Sanforizing? What are the advantages of each type of treatment?
10. What are the sources of dyestuff? From which source are most dyes now obtainable? What is a mordant? What precautions should be taken during the dyeing of a fabric?
11. How much do you think the consumer should know about the various weaves of fabrics? Where would you obtain reliable consumer information about fabrics?

12. What are the chief sources of leather? What processes are used to convert the hides into leather? Which type of tanning is considered to be more desirable? Why?

13. Exactly what consumer information would you wish to have at your command when purchasing a fur garment? How would you obtain this information?

14. How is linoleum made? Why is linseed oil rather than some other oil used in its manufacture?

15. What are the advantages and limitations of wood as a construction material?

Problem 4: How do we produce and use artificial and synthetic construction materials?

• THE PLASTIC AGE

The plastic age is not coming—it is here! From the early morning hours, when plastic combs, hairbrushes, and toothbrushes aid us through the prebreakfast rush, to late at night, when we relax with a good book by the side of a lamp fashioned from a plastic—we live in a world of everyday articles that employ these versatile materials in one form or another. Even the teeth we brush, if they are not the ones designed for us by nature, may rest in the firm grip of a plastic plate. We drink from plastic cups, we lift a plastic telephone receiver, we write with plastic fountain pens and pencils. Cases for clocks and radios; jewelry; bric-a-brac and novelties of all kinds; electric shavers; fishing tackle; insulators for heat and electricity; poker chips; and instrument panels, trimmings, gears, and steering wheels for automobiles suggest the wide variety of everyday uses to which plastics are now put—and with a high degree of satisfaction.

It would seem that the uses of plastics are limited only by human ingenuity and imagination. The makers say that these materials are already being used in more than fifty thousand different ways. The fabrication of airplane fuselages and automobile bodies from such materials has already been accomplished and may some day be commonplace. Plastic glass that can be sawed and nailed and is virtually unbreakable forecasts building materials of the world of tomorrow. Who knows but that plastic door and window frames, lighting fixtures, and floors—and perhaps even plastic wall paneling—will characterize the home of fifty years hence? Yet, despite the range of utilitarian properties available in plastics, even their manufacturers believe it unlikely that such materials will ever dis-



Courtesy Tennessee Eastman Corporation

As shown here, plastics materials are available in a wide variety of forms. They are supplied in granules, blocks, sheets, tubes, and rods; in plain or variegated colors; and in all degrees of transparency from crystal clear to opaque.

place the old "big three" of the building world: wood, stone, and metal.

Plastics have an interesting history. About the middle of the nineteenth century, there developed among manufacturers an urgent need for substitutes for ivory, tortoise shell, amber, bone, and hard rubber. Chemists set to work on the problem. To spur research, a company that made billiard balls offered a $10,000 prize to anyone finding a satisfactory substitute for ivory, of which billiard balls were then made. John Wesley Hyatt, a printer by trade, decided to try for the prize and began devoting all his spare time to experimentation. In 1868, he mixed finely ground paper and shellac together and compressed the mass into a ball; then he coated the ball with pyroxylin—a chemical substance made from cotton and nitric acid and used in the manufacture of explosives. Billiard balls made in this way sold widely; the chief drawback was that they were inflammable. Edwin E. Slosson's *Creative Chemistry* reports the assertion of a Colorado saloon keeper that one of his customers accidentally touched a hot cigar to one of these billard balls. A loud bang followed, and there stood every man with gun drawn ready for self-defense.

Undaunted, Hyatt continued his work. He mixed pyroxylin with camphor and obtained a plastic that was easily molded when hot and would harden quickly when cold. This material was named "celluloid." It was inexpensive to make and found quick acceptance for use in making washable cuffs and collars, piano keys, dental plates, knife handles, brushes, and novelties. Hyatt and his brother established a factory in Newark, New Jersey, in 1873, and a new chemical industry—synthetic plastics—was under way.

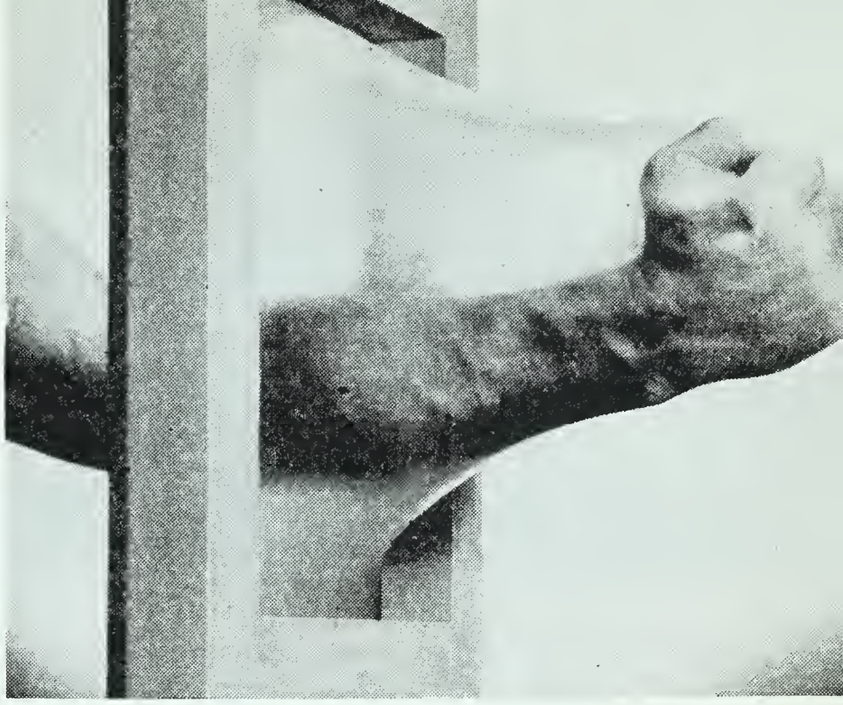
But chemists still tried to make suitable plastics that would not

be as inflammable as celluloid. In Germany in 1890, a teacher was trying to find a white substitute for making schoolroom "blackboards." One day in the course of his experiments, he mixed sour milk and the chemical, formaldehyde. The result was a hard shiny material resembling horn. It is known as *casein plastic* and is used even today for making buttons, buckles, and various novelties. So common are these articles, it is likely that everyone at some time or other wears sour-milk buttons.

At about this same time, Dr. Leo Baekeland, an American chemist born in Belgium, entered the field. He perfected a photographic printing paper and sold his patent to a famous camera company; he then began to look for other chemical problems to solve. He decided to seek a cheap substitute for the expensive shellac used in varnishes and insulating materials. Proceeding in scientific fashion, he checked the efforts of others to find out where and why they had failed. As he began experiments and watched the reactions of his materials, Baekeland saw the possibilities of a new material far more important than any substitute for shellac. By combining phenol (carbolic acid) and formaldehyde, he obtained a resinous material which could be cast or molded in any desired shape. Once formed under intense heat and pressure, the plastic acquired great strength and hardness and could not be remelted. This new material was called bakelite resinoid for its inventor, Dr. Baekeland.

Plastics are manufactured from a great variety of raw materials. Generally speaking, there are two types of plastics in use today: *thermoplastics* and *thermosetting plastics.* Thermoplastics, exemplified by celluloid, are softened by heat and can be remolded after they are formed. Thermosetting plastics, to which group bakelite phenolics belong, once formed are not softened by heat and can never be remolded. The most important plastics of the present time are built up chiefly from plant materials, animal materials, minerals, and gases from the air. Out of the test tubes, retorts, and cauldrons of chemists have come these newest of all building materials, built up molecule by molecule by modern alchemists.

Vegetable plastics. Plastics in this group have cellulose as the base; it may be obtained from wood, like spruce, or from cotton linters. If properly treated with nitric acid, *cellulose nitrate* is formed, which is used as a plastic under the general name of pyroxylin. Even though very inflammable, cellulose nitrate has long been used in making commercial motion-picture film. Film



Courtesy General Motors Corporation

This illustration graphically demonstrates the great flexibility of the plastic interlayer of high-test safety glass.

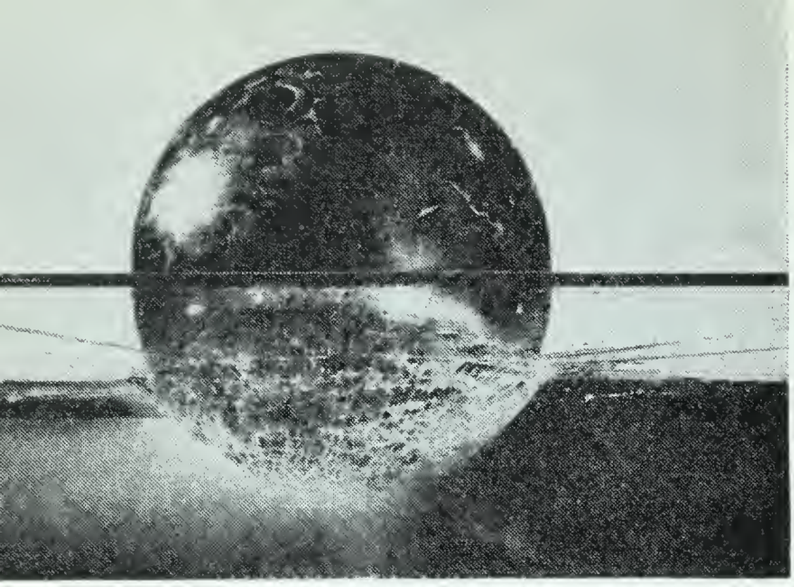
for 16 millimeter and 8 millimeter home movies is safety film made from *cellulose acetate;* this plastic is preferable because it is slow burning. In many modern automobiles, the steering wheels and trimmings are made of thermoplastic cellulose acetate in solid or variegated colors.

Mineral plastics. Plastics in this group are made from such raw materials as coal, petroleum, natural gas, salt, air, and water. There are several with many useful properties. Probably the leader in this field is the bakelite-type phenolic resinoid. These plastics are made by combining formaldehyde with phenol (carbolic acid) obtained from coal tar or manufactured synthetically. They are thermosetting. Phenolic resinoids are used especially in making telephone sets, electrical plugs, outlets, insulators, and dozens of other products.

Polyvinyl butyral is one of the newest plastics. It forms the interlayer of high-test safety glass; it gives more resistance to impact than any other material proposed for this purpose. *Polystyrene* is a related transparent thermoplastic material now much used for watch crystals and lenses; the covers over the instrument panel and clock of your automobile are likely to be polystyrene.

Acrylic plastics are tough, and, although they may be had in beautiful colors, their first claim is to unusual transparency. They let through 3 per cent more light than ordinary glass. One of these plastics, known as Lucite, has gained fame as a "light bender"; rods of it tied into knots or bent into all shapes like a pretzel carry light like a pipe carries water. The light does not pass through the walls of the rod, but travels its length and comes out only at the end—and it comes out cold.

Plastics made from formaldehyde and urea are second in importance among the thermosetting plastics being surpassed only by the phenolic resinoids. Mixed with cellulose fillers, urea plastics are widely used as molding materials. They have the advantage of taking brilliant colors which do not fade when exposed to light. Modified urea resins are much used in the manufacture of lacquers



Courtesy General Motors Corporation

This pictures what happened when a bowling ball was dropped from a height of six feet onto a sheet of high-test safety glass. Note how the fragments of glass cling to the plastic interlayer. The value to motorists of this product of scientific research is obvious.

and enamels of good durability.

Animal plastics. These plastics are represented by casein plastics made from sour milk and formaldehyde. At present, they are used chiefly for buttons, buckles, small ornaments, and the like.

Plastics are fabricated into finished products by a number of different processes. Modern plastics are generally cast or molded from a soft or granulated mass. In the production of molded articles, the liquid material is first allowed to harden; then it is pulverized and mixed with a filler such as wood-flour or asbestos. This mixture is put into molds where, under heat and pressure, it softens and then dries, forming into the desired shapes.

Plastics in the liquid state are cast by pouring the liquid into forms where it hardens. Cast plastics are supplied in rods, sheets, and tubing. These may be cut, drilled, sawed, threaded, and machined in various ways to produce a multitude of finished articles.

Plastics can be made into the form of paints and varnishes which, when properly applied, give a lustrous and durable finish. In the manufacture of gear wheels or paneling for radio cabinets, instrument panels, and the like, pieces of cloth or paper are dipped into such a varnish and allowed to dry. The stiffened paper or cloth is then cut into pieces of the size and shape desired. The pieces are piled on top of one another. When subjected to great heat and pressure, they solidify into one sheet. This is called a *laminated plastic,* because it is built up of many layers. The cloth or paper acts as a reinforcement and makes a laminated plastic sheet tougher and stronger than a plain, cast sheet.

Plastics of all kinds can now be electroplated with thin coatings of gold, silver, and other metals. A recently developed process of giving the plastic a bonding coat to which the metal will adhere has made this possible.

Use of plastics in the airplane and automotive industries has helped lessen the burden of producers of light-weight metals.

• ARTIFICIAL RUBBER FROM — WELL, MANY THINGS

Man-made rubber is today not only a possibility, it is an actuality. One ideal for which scientists of all nations strive is the practicable production of materials to substitute for essential ones which must usually be imported from other countries. The successful solution of such a problem makes their country independent of foreign supply sources during times of stress or emergency. Oftentimes the new product is better than the natural one, at least for certain uses.

Such production of rubber has engaged the interest and efforts of experimenters for many years. Today, several types of artificial rubber are known, and some are in commercial production, both in the United States and abroad.

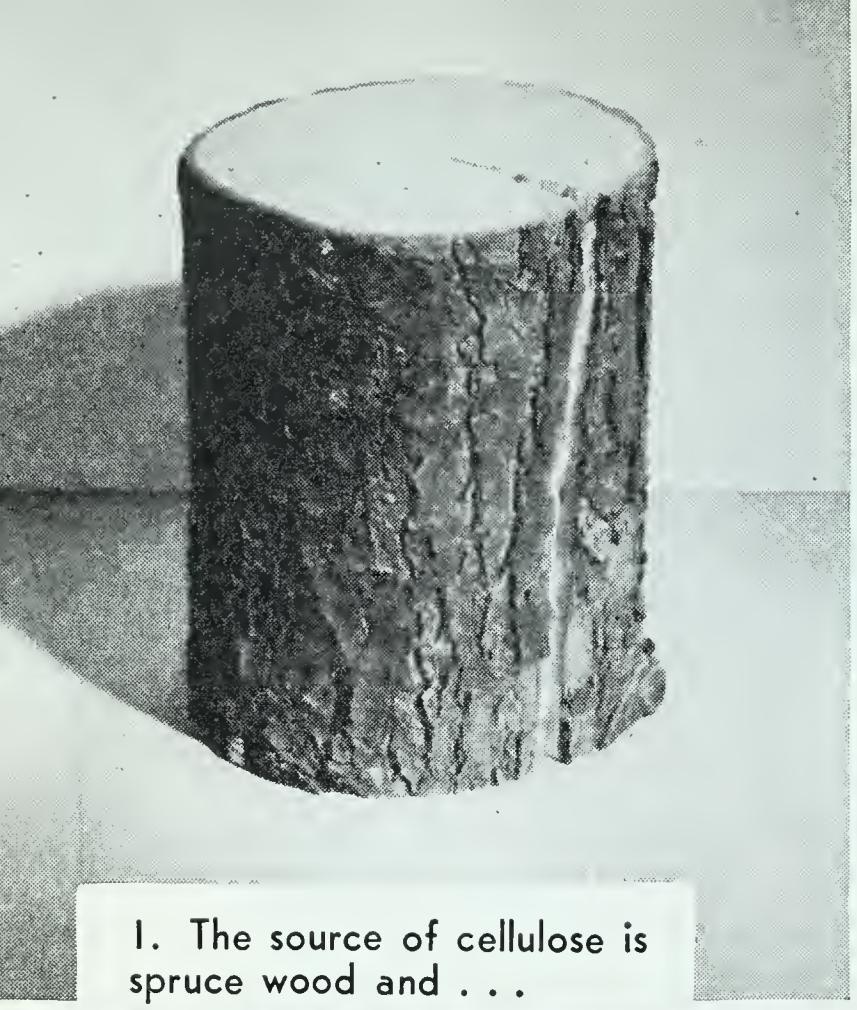
Neoprene is an American product and perhaps the best known of the various artificial rubbers. It was put on the market about 1936, and its use has been increasing ever since. Neoprene is manufactured from such raw materials as coal, limestone, salt, and water.

Within recent years, several types of artificial rubber developed through research have been produced from petroleum. Regular production of these "Buna" types of rubber, as they are called, is now being carried on by several companies. The recent war emergency has naturally led to great expansion in the synthetic-rubber industry.

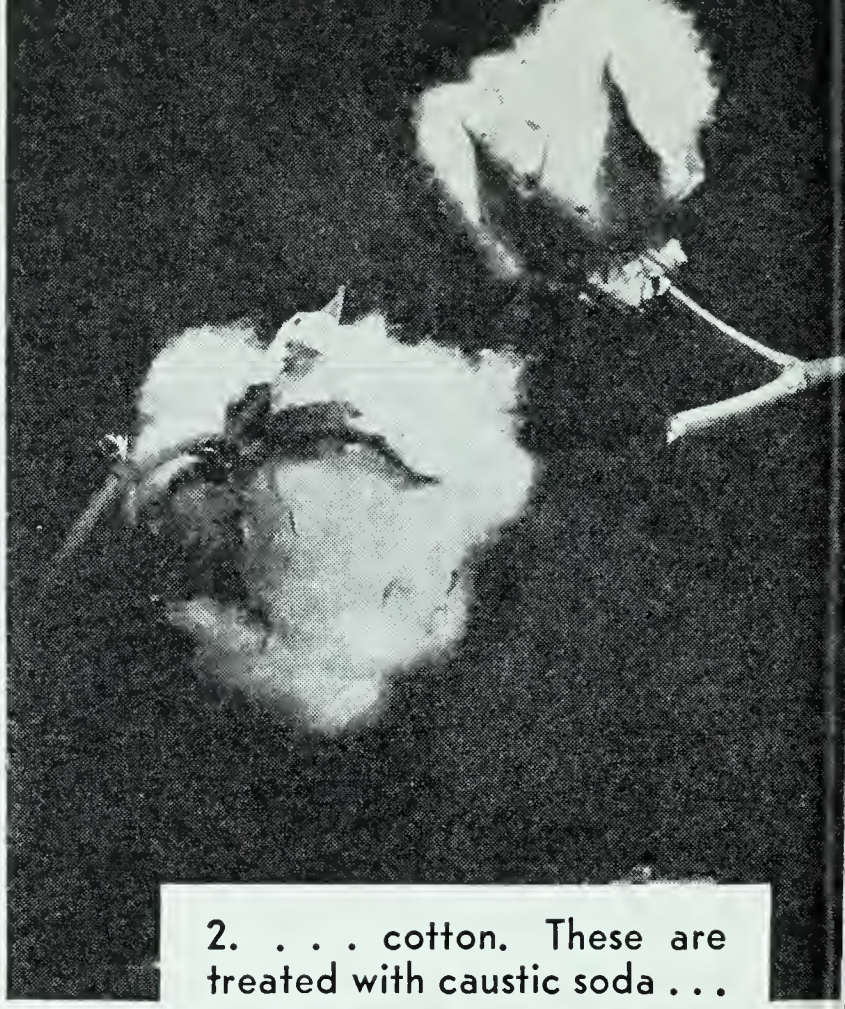
The present uses of the various kinds of artificial rubber are due to their superior qualities. Manufacturing costs are high, and the present prices of artificial rubber are much higher than for natural rubber. Nevertheless, many products are made from various kinds of artificial rubber of one kind or another. In general, these synthetics are all characterized by greater resistance to aging and oxidation; to the effects of heat, light, acids, and alkalies; and to the swelling action of grease, gasoline, kerosene, and other solvents. At least one type is superior to natural rubber as an electrical insulator.

Artificial rubber is compounded in the same way as natural rubber, using identical methods and machinery. The finished articles are vulcanized in the same manner as those made from natural rubber.

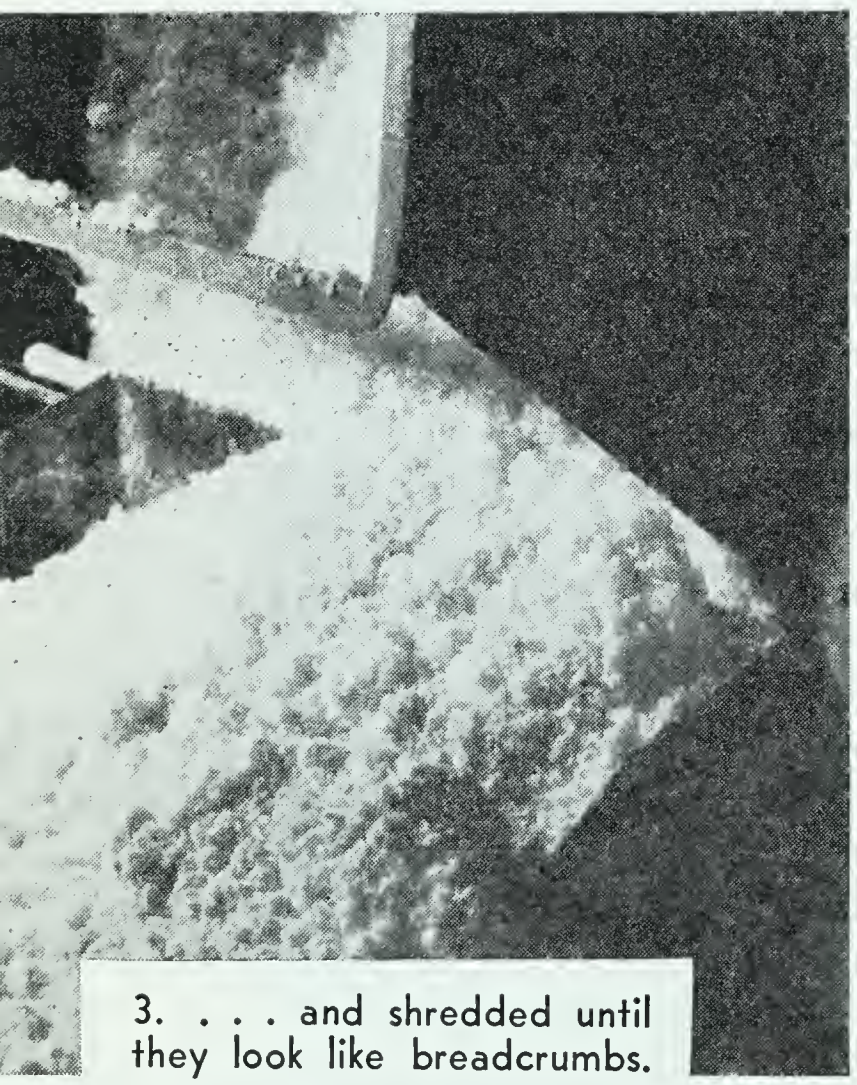
Thus, through the magic of chemical research, man has made another notable adjustment in his never-ending quest for construction materials.



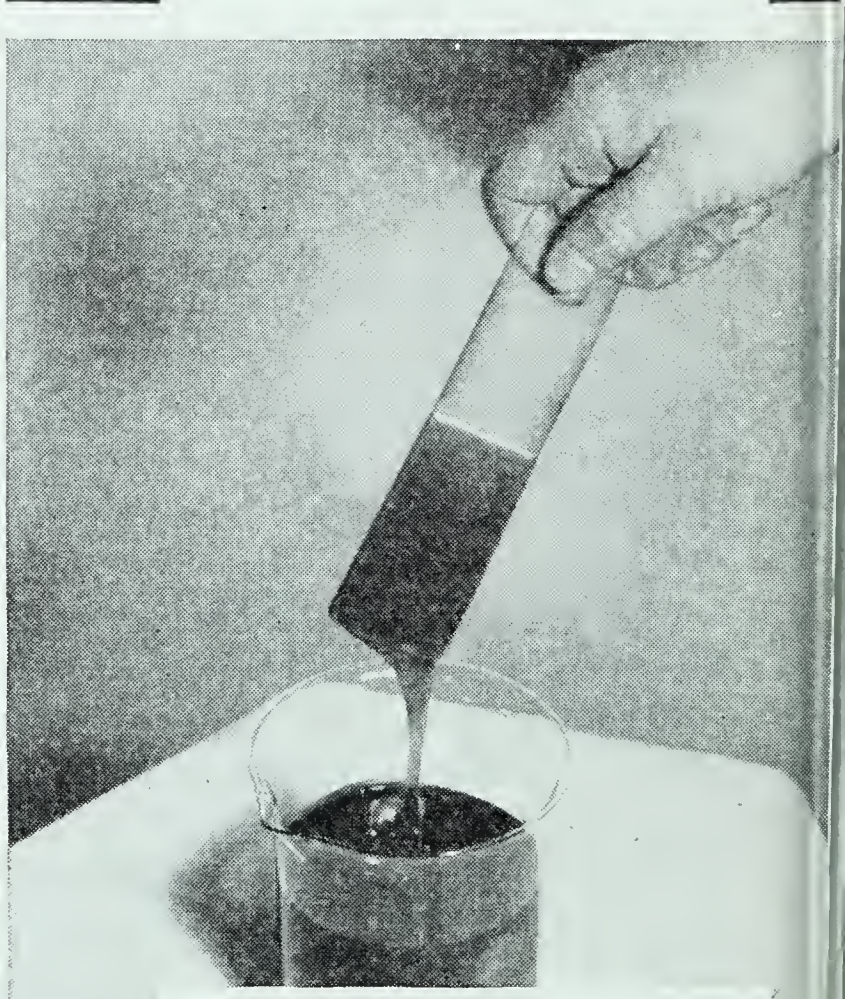
1. The source of cellulose is spruce wood and . . .



2. . . . cotton. These are treated with caustic soda . . .



3. . . . and shredded until they look like breadcrumbs.

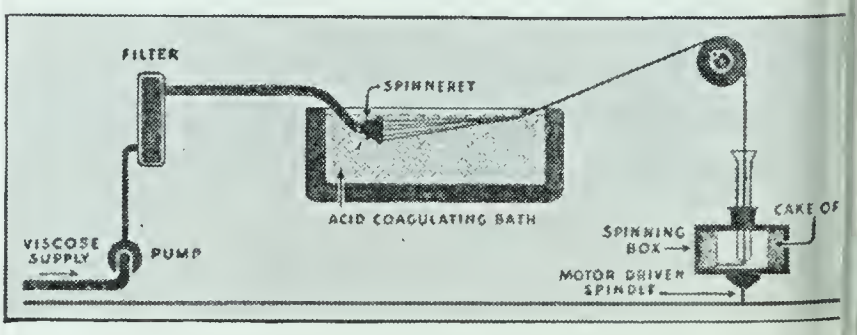


4. Treatment with carbon disulfide produces a liquid called viscose, which is converted into yarn.



5. Yarn from spinning machines is washed, bleached.

Courtesy The Viscose Company



6. Rayon manufacturing is traced from viscose form until the yarn is wound.

• TEXTILES FROM TEST TUBES

Rayon is the most popular man-made fiber. It is really a modified form of cellulose and may be prepared from cotton, cotton linters, or certain kinds of wood. The general steps in rayon manufacture consist of dissolving cellulose in a suitable solvent and forcing the resulting solution through tiny sievelike openings into a chemical bath. Here the stream of cellulose hardens into a threadlike fiber. There are several different processes for making artificial fibers from cellulose, but the product of every one is called rayon regardless of how produced.

In the nitrocellulose method, cellulose nitrate, or pyroxylin, is dissolved in a mixture of ether and alcohol to form a sirupy solution called *collodion.* When this solution is forced through minute openings into dilute sulfuric acid, the cellulose re-forms in fine filaments. However, the product must be denitrated or it is highly inflammable.

Cellulose-acetate rayon, often called *Celanese,* is formed in a somewhat similar fashion, except that the raw cellulose is treated with acetic-acid anhydride (acetic acid minus water) instead of nitric acid.

The viscose process is used to produce more than three-fourths of the nearly three hundred million pounds of rayon made annually in the United States. The product is often referred to as *viscose rayon.* Wood pulp and cotton linters are generally the source materials. They are chemically treated with sodium hydroxide and then with carbon disulfide. The result is viscose, a sticky solution resembling brown molasses. This solution is forced through tiny openings into a hardening bath of acid, from which the cellulose emerges as smooth, tubular filaments. Several filaments are twisted together to form threads, and the threads are wound into skeins. The skeins are treated to remove excess chemicals; then they are bleached, washed, dried, and humidified.

Nylon is the first artificial fiber made from all-mineral raw materials. It is produced by intricate manufacturing processes from coal, air, and water. Nylon was first introduced as toothbrush bristles, but several commercial articles are now made of this artificial fiber, the most notable of which are stockings. Nylon fibers are smooth and have the feeling and luster of natural silk. If anything, they are stronger than silk; stockings made of Nylon are therefore more resistant to runs.

Polyvinyl-acetal plastic can also be produced in fibers as fine and

virtually as strong as silk, waterproof, and fireproof. Thus it also has possibilities as a substitute for silk. *Vinyon* is the name assigned to this artificial fiber, and it has already entered into the manufacture of industrial filter cloths, fishing nets, and several types of thermoplastically bonded felts.

Recently, newspapers announced that chemists had succeeded in making "wool" from sour milk. It is true that an artificial fiber has been made from casein, but it is not really wool. However, its properties closely resemble those of wool, and it seems probable that, even in this country, this fiber will sooner or later be used to make the supply of real wool go farther at lower cost. *Casein wool* resulted from chemical research carried on in Germany and Italy.

Exercises for Problem Study and Review

1. Which of our present-day plastics date back to the last century? How were they made?
2. What is the important physical difference between thermoplastics and thermosetting plastics?
3. What property of Lucite-type plastics gives them special uses not shared by other plastics? What are some of these uses?
4. What methods are used to make finished articles from plastic materials?
5. What is a laminated plastic? What advantage does it have over ordinary cast plastic?
6. What are the advantages of artificial rubber as compared to natural rubber? The disadvantages?
7. Outline the different ways in which rayon is made. Why has rayon become so popular? Has it any disadvantages?
8. What properties account for the rapid popularity gained by Nylon?
9. Does wool have any artificial competitor as does silk? Explain.

Problem 5: How do we care for and preserve construction materials?

Wise consumership involves more than careful selecting and buying. The intelligent consumer takes good care of things after he purchases them. Wood rots and decays, and metals rust, tarnish, and corrode. Cement and natural stone are acted on by acids, and they slowly disintegrate as the result of freezing and extreme temperature changes. Rubber, paper, leather, and textiles—even

plastics—deteriorate in time. Every known construction material finally yields to the destructive agencies of nature.

Clothing needs to be dry-cleaned and laundered and to have spots and stains removed. One has to guard against such pests as moths and termites. Kitchen pots and pans are frequently cleaned and polished. Tarnish must be removed from silverware. This enumeration suggests a few of the maintenance jobs of the individual householder.

Industrial concerns and governmental units also attempt to consume wisely by intelligently caring for and preserving materials. Nearly every company, large or small, has a maintenance crew or department. Cities, counties, and states spend large sums of money repairing roadways, streets, and all manner of public property. From silk handkerchiefs to skyscrapers, every article and structure presents a maintenance problem. Thus we see that man must wage a constant battle with nature to retain possession of construction materials.

• CARING FOR METALS

The corrosion of metals is another example of oxidation. When iron rusts, oxygen from the air combines chemically with iron to form iron oxide:

$$\begin{array}{ccccc} \text{iron} & + & \text{oxygen} & \rightarrow & \text{iron oxide} \\ 4Fe & & 3O_2 & & 2Fe_2O_3 \end{array}$$

Experimentation shows, however, that iron will not rust in perfectly dry air; some moisture must be present. In some cases of corrosion, as for example that of lead, copper, and zinc, carbon dioxide takes the place of oxygen, but moisture is still needed. Hence we conclude that the three chief agencies of corrosion are water, oxygen, and carbon dioxide, with water apparently the most important. Other agencies of corrosion are sulfur dioxide and hydrogen sulfide, both of which are likely to be present in the air around certain factories and wherever soft coal is burned. The tarnish on silverware is caused by hydrogen sulfide of the air or the sulfur content of certain foods.

The principle of preventing the corrosion of metals is well set forth in the slogan of paint manufacturers—"save the surface and you save all." The chief methods of applying this principle consists of coating the exposed surfaces with (1) paints, lacquers, vitreous (glasslike) enamels, and the like; (2) grease and oil; (3) more resistant metals; (4) chemical compounds. Iron is the chief metal that needs protection.

Since enamels are impervious to water, they prevent corrosion of the underlying iron in bathtubs, sinks, and enameled signs as long as the enamel is continuous. However, once the enamel coating chips or breaks, rusting begins and spreads in all directions underneath the rest of the enamel. Paints, lacquers, and related protective coatings behave in similar fashion. Various articles of aluminum, brass, or silver are commonly protected against tarnish by painting them with a clear lacquer. Although grease and oil dissolve oxygen and permit it to penetrate to the metal underneath, they keep water away from the metal and thus protect against oxidation.

Many metals act as guards against corrosion. Zinc and tin are the two metals most commonly used to protect iron; others are nickel, chromium, aluminum, silver, and copper. All iron that has been coated with zinc is called *galvanized iron,* while iron that has been coated with tin is known as *tin plate.* Zinc, aluminum, and chromium are more active than iron, and we may well wonder how they guard against corrosion. The answer is that even though these metals do undergo chemical change when exposed to agencies of corrosion, the product that forms on their surface acts like a "skin" or protective film and effectively hinders further corrosion. These films are very thin and usually do not impair the appearance of the metal, although they dull the luster considerably except in the case of chromium.

Metallic coatings are applied in a number of ways. Probably the oldest method is *hot dipping,* in which the metal to be applied is melted and the thoroughly cleansed ironware to be protected is dipped into or drawn through the bath of liquid metal. Zinc and tin are commonly applied by this method to sheet iron, iron wire, and all manner of objects made of iron.

Electroplating is another important method of applying metallic coatings. The object to be plated is thoroughly cleaned and attached to the cathode (negative), and a bar of the plating metal is attached to the anode (positive); both are immersed in a chemical solution of the plating metal, and a properly regulated direct current is turned on. The current causes atoms of the plating metal to leave the anode, pass through the solution, and deposit on the cathode. Practically every metal can be applied by electroplating if desired.

Small objects of irregular shapes are sometimes treated with zinc by heating them in an iron drum along with the powdered metal. The metal vaporizes and deposits on the iron base so as to form a

firm adherent coating conforming sharply to the original outline of the object being coated. *Sherardizing* is the name of this process; aluminum is similarly applied by *calorizing.*

By means of the *Schoop process,* metals can even be sprayed upon the surface to be protected. The metal is fed into the "gun" in the form of wire. Provision is made to melt the wire, and a blast of air forces the metallic mist onto the surface being treated.

Sometimes iron is rusted to prevent further rusting. Ordinary red iron rust is loose and porous, and the agencies of corrosion readily penetrate to the metal underneath. By chemical treatment, however, it is possible to produce black iron oxide on iron in the form of a continuous, adherent coating which effectively "seals out" moist air, thus protecting the metal. Iron and steel products are also rustproofed by treating them with phosphoric acid. This causes millions of crystals of iron phosphate to form on the surface, giving a "skin" that is nonporous and adherent. Treatment with oil improves the appearance of this finish and increases its water-repellent quality.

When metals become tarnished or rusty, they should be cleaned. The cleaning and polishing of metals nearly always involves (1) the scouring action of certain abrasives; (2) the dissolving action of some solvent; or (3) chemical action, usually with an acid. Scouring and polishing agents should be used cautiously, and the comparative hardness of the abrasive material and the metal should always be taken into account. Kerosene and gasoline are effective in removing grease and oil from metals; remember, however, that these two liquids form highly inflammable vapors. Acids and alkalies also remove grease, but their action on the metal is sometimes destructive. Strong acids attack iron, zinc, and aluminum rapidly, tin more slowly; alkalies destroy aluminum, zinc, and lead.

The following paragraphs give recommended procedures and treatments for use in cleaning various metals. Happily, the increasing use of vitreous enamels, stainless steels, heat-resistant glassware, and nontarnishing alloys is relieving the housewife of much of the drudgery of cleaning and polishing.

Aluminum. Cooking foods containing soda or other alkaline substances in aluminum utensils causes a dark tarnish to form. It can be removed by cooking an acid-containing material in the vessel or by allowing a warm solution of oxalic acid to stand in the vessel for several hours. Thoroughly wash the utensil afterward as *oxalic acid is highly poisonous.* Aluminum utensils are hard enough to stand the scouring action of steel or copper wool.

Zinc and galvanized iron. Avoid the use of hard abrasives and steel wool, for zinc is a comparatively soft metal. Zinc surfaces can be cleaned and polished by using a paste made of kerosene and whiting (especially prepared calcium carbonate).

Iron. There is no completely satisfactory method of cleaning rust from iron. Kerosene and solutions of ammonium or sodium citrate are recommended to loosen rust. Mechanical methods, such as the use of emery cloth or steel wool, are probably best for getting a clean, bright surface.

Copper, brass, and bronze. Oxalic acid and whiting applied as a paste, allowed to dry, and then brushed off will remove tarnish and polish the metal. A mixture of salt and vinegar or lemon juice is also recommended. A mixture of soapsuds and ammonia water or a dilute alum solution will remove tarnish from bronze.

Gold and silver. Beware of all hard abrasives, metal wool, and questionable polishes. Use only the mildest abrasives in cleaning these two metals. The following formula is recommended as giving excellent results:

Whiting	30 grams
Alcohol, denatured ethyl	45 cubic centimeters
Ammonia water	200 cubic centimeters

Apply as a paste, allow to dry, and then rub briskly with a soft cloth. A good silver polish can be made at home by mixing whiting and household ammonia water into a thin paste, which is used in the manner just described.

Likewise, beware of silver-plating solutions, such as those frequently sold by street vendors and supposed to be used in the home to restore silverware. They are likely to contain mercury compounds, which are extremely poisonous. Furthermore, the finish produced by dipping the article into the solution is a deposit of mercury; it is bright and shiny at first, but does not last long.

The *silver clean pan* is a device for cleaning silver by electrolytic chemical action. Various forms have appeared on the market, but an aluminum pan serves as well as the others. The only precaution is that, before using the pan, it should be scoured bright and clean on the inside. The pan is filled with a hot solution of baking soda and table salt (about one teaspoonful of soda and one tablespoon of salt to a quart of water) and the silverware is put inside in contact with the aluminum pan for a period of time. The pan itself, however, receives a coating of tarnish during the chemical action. Bear in mind that any decorative coloring on

the silverware is quite similar to tarnish, and its distinctive appearance will likely be marred by this method of cleaning. However, there is no loss of silver by this method as there is with silver polish, because the tarnish is chemically changed back into silver.

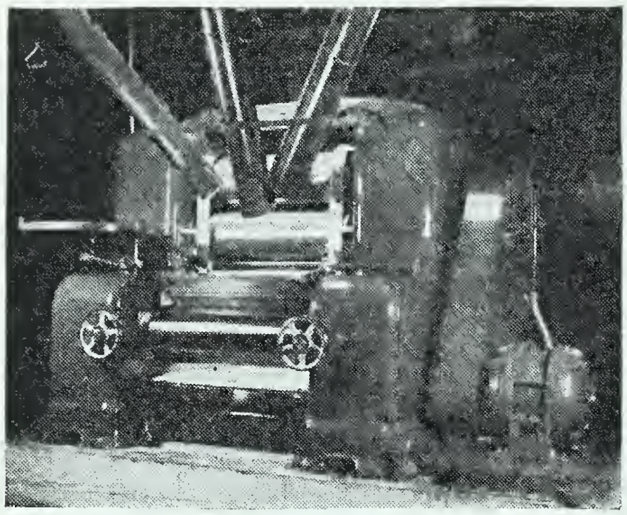
• CARE AND PRESERVATION OF WOODWORK

The chief enemies of wood are rot and termites. Decay takes place in wood which is quite moist but not saturated with water. Neither dry wood nor thoroughly soaked wood will decay if kept in that condition. Samples of wood showing no signs of deterioration have been taken from buildings hundreds of years old in which conditions have been favorable. Likewise, wood in an excellent state of preservation has been taken from the bottom of lakes or old wells after hundreds of years of submergence. In the average dwelling, decay is most likely to occur in posts or sills in contact with the ground; in beams in damp cellars; at the base of porch columns; on the unexposed surface of siding; in wood underneath leaks in roofs, drains, water pipes, or around pipes and tanks that "sweat"—in fact, wherever moisture is likely to accumulate and in hidden parts not exposed to the drying action of circulating air.

Termites or "white ants" are very destructive to wood, especially in certain sections of the country—the South Atlantic states, the Gulf states, and some regions of the Middlewest. Termites live in wood which is in contact with or can be reached from the ground. They eat the cellulose and often completely riddle wooden timbers and boards, leaving only a thin, weak shell of the former structure. The ravages of "white ants" can largely be forestalled by keeping all wood free of contact with the soil or by using timbers treated with creosote. Untreated lumber should never be completely surrounded by masonry, as this prevents drying of the timbers and increases the likelihood of decay and attack by termites. Once termites begin their work in a structure, the services of an expert are nearly always necessary to get rid of them.

Probably the first step in avoiding decay is to use well-seasoned lumber. In situations favorable to decay, even "the best is none too good." Try to maintain conditions that foster rapid drying. Sills and posts should be supported on stone or concrete piers and footings that extend well above the ground.

Exterior woodwork and exposed surfaces should be well painted, especially where there are joints or cracks. This prevents the rapid absorption of rain water with resultant decay. However, well-



Courtesy The Lowe Brothers Company

The roller mill grinds paint pigment.

painted wood kept in constantly moist conditions will ultimately absorb just as much moisture as unpainted wood.

Wood can be chemically treated to increase resistance to rot and termites. Creosote, a strong-smelling product obtained from coal tar, is a commonly used preservative. Railroad ties, the lower ends of telegraph poles, piling timbers, fence posts, and the like are often treated with creosote. It is advisable to apply with a brush two coats of hot creosote to the base of posts in cellars and to sills and porch timbers which are likely to be moist or which touch or lie near the ground.

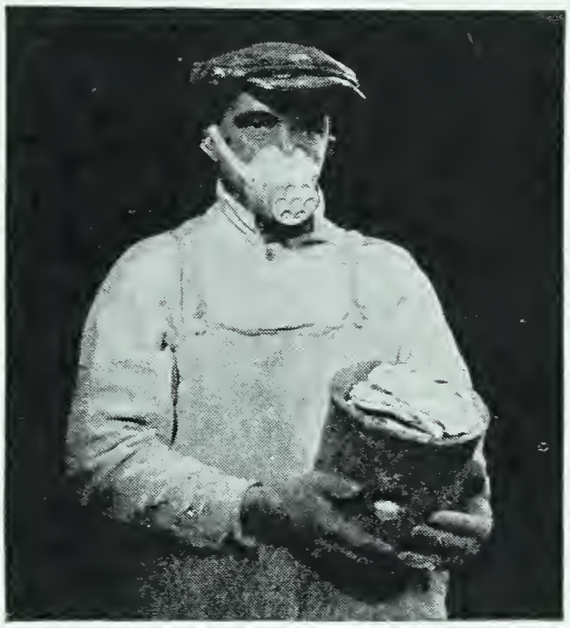
Timbers are sometimes given preservative treatment with solutions of zinc chloride or sodium fluoride, either by application with a brush or by injection under pressure. The latter method greatly increases cost, but the brush method is not sufficiently effective in retarding decay to make it worth while. Sodium fluoride is poisonous and, when properly applied, greatly retards termite activity.

• PAINTS FOR BEAUTY AND PROTECTION

All paints consist essentially of two parts—the liquid portion and the solid portion. The chief solid in paints is called the *pigment;* it is a finely divided substance, either white or colored, which provides good hiding power and results in an opaque coating on the surface to which the paint is applied. The pigment is suspended in a drying oil called the *vehicle.* Linseed oil has long been the favorite; it is used either raw or chemically treated and heated to form "boiled" linseed oil. Today, however, soybean oil, sardine oil, sunflower-seed oil, and tung oil are much used. Tung oil is imported mostly from China, but attempts to cultivate tung trees in our Southern states are meeting with increasing success. When paints containing these oils are applied to wood, metal, or other surfaces, the oil unites chemically with oxygen and forms first a gel, then a hard, tough, elastic film.

In addition to pigment and vehicle, paints usually contain *thinners* such as turpentine which make them easier to apply. Thinners

quickly evaporate after the paint is applied. Most paints also contain some material such as ground talc, gypsum, white clay, or asbestos to give strength and toughness to the resulting film; these materials are called *reinforcing agents*. According to the United States Forest Products Laboratory, the most satisfactory fire-retardant paints are linseed-oil paints containing finely ground borax.



Courtesy National Lead Company

The worker holds a crock filled with lead buckles. It is in these crocks that the chemical reactions take place which result in the formation of white lead.

There are only five white pigments of good covering power. They are white lead, sublimed white lead, zinc white, lithopone, and titanium oxide.

White lead is made principally by the so-called *old Dutch* process. Lead is cast into the form of buckles, which are then loosely stacked in earthenware crocks of special design. The lower part of each crock is a small compartment filled with acetic acid. Where the crock narrows to form this compartment, a ledge is formed which supports the buckles above the acid. The filled crocks are stacked in tiers in a special room and allowed to remain there. Each layer of crocks is covered with tanbark which slowly ferments, forming carbon dioxide and giving off enough heat to vaporize the acetic acid. Chemical reactions occur between the lead, acid, and carbon dioxide which result in the formation of basic lead carbonate, or white lead.

Zinc white is really zinc oxide. It is prepared by the direct oxidation of zinc:

$$\begin{array}{ccccc} \text{zinc} & + & \text{oxygen} & \rightarrow & \text{zinc oxide} \\ 2\,\text{Zn} & & O_2 & & 2\,\text{ZnO} \end{array}$$

White-lead paints tend to darken on exposure, because atmospheric hydrogen sulfide causes the formation of black lead sulfide. Zinc sulfide is white. For this reason and also because they are not poisonous, zinc paints have distinct advantages over white-lead paints. White-lead paints are very popular, however, because of their greater covering capacity. In actual practice, zinc white and

white lead are generally used in mixtures which retain most of the advantages of each and at the same time avoid many of their disadvantages.

Sublimed white lead is made by heating the mineral form of lead sulfide, galena. The result is a white material composed principally of basic lead sulfate. If the galena contains much zinc sulfide, as is sometimes the case, the resulting pigment is a mixture of lead sulfate and zinc oxide. Such pigments can also be made by mixing these two chemicals in various ratios; they are known as leaded zinc pigments.

Lithopone is a favorite white pigment made by chemical action between zinc sulfate and barium sulfide:

zinc sulfate + barium sulfide → zinc sulfide + barium sulfate
$ZnSO_4$ BaS ZnS $BaSO_4$

Both products of this reaction are white and insoluble. Lithopone finds extensive application in the making of interior wall paint, white leather, window-shade cloth, and cosmetics. It is also used as a pigment and filler in rubber and as a pigment in making linoleum and oilcloth. Paints containing lithopone are used chiefly for inside work, although modern lithopones are also suitable for outdoor application.

Titanium dioxide is one of the best all-round white pigments. Paints containing this pigment are very white and durable and have excellent covering capacity.

Dozens of colored substances have been used in paint manufacture. Sometimes the colored pigments alone are used, but more often they are mixed in correct amount with various white pigments to give the desired result. Used for this purpose are oxides of iron and lead and certain sulfides, chromates, and other colored compounds of the metals. Various forms of carbon and many coal-tar dyes also find their way into paint manufacture.

Quick-drying lacquers contain the well-known material—pyroxylin. It is dissolved in a suitable solvent which quickly evaporates and leaves the nitrocellulose in the form of a continuous film. Natural or synthetic resins are incorporated into lacquers to make the pyroxylin film adhere better and to enhance its gloss. As in paints, various pigments provide covering power, give desired colors, and make the film opaque to light. If precautions were not taken, pyroxylin films would quickly become brittle, like old celluloid, and crack when bent. High-boiling liquids, called plasticizers, are added in making lacquers to keep the film flexible and

to prevent this occurrence. Lacquers can be applied to both wood and metal. They give an attractive finish that affords excellent protection against the agencies of corrosion. Since they dry quickly because of the rapid evaporation of the various solvents, they are usually applied by spraying with the aid of compressed air. The development of quick-drying lacquers has reduced the time required to paint an automobile from a matter of weeks as in 1925 to a matter of hours today.

Varnishes give protection without hiding the beautiful grain of wood. Essentially, varnishes are solutions or partial solutions of certain gumlike materials in suitable solvents. There are two general classes of varnishes: spirit varnishes and oil varnishes.

Shellac is a typical *spirit varnish* and the most important of this class. It is made by dissolving the resinous material, shellac, in methyl (wood) alcohol. As the alcohol evaporates, a film of the resin is left covering the surface treated. Shellac resin originates as the secretion of the lac insect, which is found in India. The female punctures the bark of certain species of trees and feeds on the sap. At the same time, she secretes lac to form cells in which to deposit her eggs. From the hard coating formed, shellac gum is manufactured.

Oil varnishes are composed of natural or synthetic resins, a volatile solvent or thinner, a drying oil, and driers. Tung oil is the favorite drying oil for use in varnish manufacture, although many high-grade varnishes are made with boiled linseed oil. Several natural gums have long been used in varnish manufacture, but most of the better grades of varnish made today contain synthetic resins manufactured on a large scale by chemical processes. Rosin is used in making the cheaper grades of varnish; it is obtained as a residue in the distillation of turpentine.

When varnish is applied, the thinner evaporates and leaves a gumlike coating of resin and drying oil. The oil oxidizes, as in paints, and assists the resin in forming a hard, durable, and lustrous protective coating. Driers are chemical substances which promote the oxidation of the oil.

The enamel paints frequently used for interior or decorative work are really pigmented varnishes; that is, they contain white or colored pigments like paints, and they contain resinous materials like varnishes.

There are other paintlike preparations of interest and utility. *Shingle stains* are similar to ordinary paints; however, they are much thinner and usually contain coal-tar creosote intended to aid

in preserving the wood. Shingle stains are often applied with a brush after the shingles are nailed into place, but the best method is to dip the shingles into the stain. Why do you think this is so?

Wood stains are exceedingly thin paints which are used primarily to modify the color of wood or to bring out contrasts of grain, rather than to protect the wood. Sometimes coal-tar dyes are used instead of pigments to obtain colors. Water stains are solutions of dyes in water. Their disadvantages are fading and "raising the grain" of the wood.

Bronze and aluminum-bronze paints, such as are often used for coating pipes and radiators, consist of finely divided metal suspended in "banana oil," a solution of nitrocellulose in amyl acetate. Sometimes these paints are made with varnish and a thinner instead of banana oil, because the latter has a disagreeable odor.

Luminous paints do not contain phosphorus, but they have the property of phosphorescence—that is, they glow in the dark. These paints contain certain metallic compounds which have been exposed to radioactive minerals, causing them to become luminous. Sometimes a very small amount of radioactive mineral is incorporated into the paint itself.

Calcimines are cold-water paints which have whiting, clay, silicates, and the like as their base instead of lime, as in the case of *whitewash.* Usually a binder like glue or casein is added to make them adhere better. Both calcimine and whitewash can be tinted by the use of proper coloring agents.

Observe these precautions when you paint. *Select the right paint for the job.* The following quotation from the National Bureau of Standards, Bulletin 70, makes clear this precaution:

"Do not use any paints containing compounds of lead about stables or outbuildings where the fumes from decaying organic matter occur, since these gases are likely to darken the lead paints. Do not use with lead compounds any pigments which may liberate compounds of sulphur. For example, ultramarine blue, which contains sulphur in a form in which it may be set free, is a beautiful and very permanent blue and may be used with zinc white but should not be used with white lead or any other lead pigments. Prussian blue, on the contrary, does not contain sulphur and may be used with lead pigments."

Be careful to avoid fire. Remember that turpentine, benzine, amyl acetate, and many other liquids used in paints are very inflammable. Keep all open flames away. Hang paint-covered clothes,

overalls, and the like out in the open to avoid fire by spontaneous combustion.

Remember that many paint pigments are poisonous! Be sure to remove all paint stains from your skin, especially before eating. To clean paint from the skin, use linseed oil rather than turpentine or benzine, and follow with a thorough washing with soap. Avoid getting paint into your mouth. Do not eat in paint-covered clothing.

There are numerous paint and varnish removers. Most of the preparations on the market consist of various mixtures of benzene, acetone, methyl alcohol, or other organic solvents. A very effective paint remover recommended by the Bureau of Standards can be prepared cheaply by dissolving sodium hydroxide (lye) in water at the rate of one pound to the gallon. It should be applied while hot with a fiber brush. However, do not try to make this solution in an aluminum vessel (Why not?), and remember that lye is hard on the hands! Lye solution raises the grain of wood, but this can be remedied by afterwards washing the wood thoroughly with water, allowing it to dry, and sandpapering.

Probably the most efficient way of removing old paint and varnish from flat surfaces is to burn it off with a torch. Heat causes the paint film to soften so that it can be scraped off. However, there is always some scorching of the wood and more or less fire hazard.

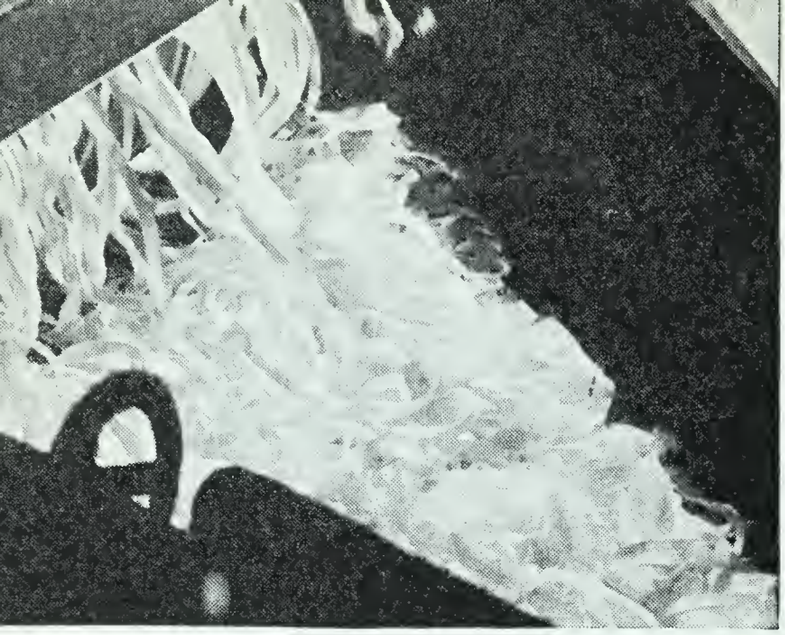
• CARE OF CLOTHING AND FABRICS

Laundering with soap and water is the most common home procedure in caring for fabrics. Probably most women realize that almost any garment or material can be successfully home-laundered if the right method is used. Silks, woolens, and certain artificial fibers require special care and treatment, but the specific techniques are quite generally known by all women who have need for them. Department stores and the many sources of consumer information gladly offer advice along these lines to all who desire it.

Here are a few "dos" and "don'ts" which ought to be observed as aids to the successful laundering of all fine fabrics:

Remember that, in general, hot water, strong soaps, and hard rubbing or wringing are ruinous to fine fabrics such as silks and woolens, particularly if they have delicate colors.

Make plenty of suds with a mild or neutral soap and lukewarm water, and then gently squeeze or force the suds through the garment. Do not rub. Work quickly.



Courtesy The Procter and Gamble Company

Ribbons of soap are formed in one of the last stages of the manufacture of soap flakes.

Rinse thoroughly in several changes of lukewarm water until the water is clear. Do not rinse woolens in a light suds so that some soap is left in the fibers.

After rinsing, press out excess water as completely as possible; then roll the garment in a Turkish towel to complete the process.

Do not hang up knitted garments to dry. Stretch them to the proper size, and allow them to dry flat on a bath towel or a clean sheet folded several times. To prevent shrinkage of wool stockings and gloves, dry them on forms.

Use the correct temperature and technique when ironing. Use no higher temperature than is necessary to smooth out the wrinkles. Nearly all fabrics lose strength if ironed at too high a temperature; acetate rayon (Celanese) may even be melted by a hot iron.

Soaps for laundering and other purposes are made from fats and alkalis. During colonial times in our country, a common household task consisted of extracting potash from wood ashes and boiling this with waste animal fats and greases from the kitchen to make soap. In modern soap factories, essentially the same raw materials are used to make soap, but, of course, on a much greater scale—sometimes the soap kettles hold as much as 250 tons. The fats and oils most commonly used today are garbage grease, waste animal fats from the slaughterhouse, and a number of vegetable oils, including cocoanut oil, palm oil, olive oil, cottonseed oil, peanut oil, and linseed oil. The principal alkalies used are sodium hydroxide and potassium hydroxide.

There are a number of methods by which fats and alkalies are made into soap, but, in all, the essential chemical change is identical. It may be represented as follows:

$$\text{alkali} + \text{fat} \rightarrow \text{soap} + \text{glycerin}$$

If sodium hydroxide is used, a hard soap will be formed, but if potassium hydroxide is used, a soft or liquid soap will be formed.

Since soap is formed by definite chemical reactions, the amounts of fat and alkali must be carefully regulated; otherwise free fat or

free alkali will be present in the finished product. Free fat prevents soap from lathering, while free alkali is injurious to the skin and to such fabrics as silk and wool.

In a common method of making soap, a measured quantity of oil or melted fat is run into the huge soap kettle, and sodium hydroxide solution is added in correct amount. The mixture is constantly stirred and is heated by steam coils which line the kettle. When the soapmaking reactions are complete and the mixture has attained the right consistency—a process which may take several days, common salt is added. Since soap is insoluble in concentrated salt solution, it rises to the top. This procedure is known as *salting out*. *Glycerin* is separated from the underneath layer of salt solution; it has many uses—in making explosives, lotions, cosmetics, and shaving creams and as an automobile-radiator antifreeze. The crude soap is treated to remove impurities and is finished in one of two ways.

In making *framed soaps,* perfumes, colorings, abrasives, and other ingredients are incorporated into the soap depending upon the purpose for which it is to be used. Then it is run into large molds where it is allowed to harden to the proper degree, after which it is cut into cakes or bars and stamped. Laundry soaps and other soft cake soaps are generally framed soaps.

Milled soaps, illustrated by the harder cake toilet soaps, are made by an alternative method. The principal feature of milled-soap manufacture is that the crude soap is allowed to dry and is then finally ground in special mills. At this point, the various ingredients of special soaps are mixed with the soap powder, and it is formed into cakes by great pressure. Milled soaps nearly always have a much lower water content than framed soaps. They lather more slowly but generally last longer.

The many varieties of soap are characterized by special ingredients. *Floating soaps* are made by forcing air into the soap in minute bubbles, which decrease its average density to less than that of water.

Transparent soaps may be made by dissolving soap in alcohol, filtering, and evaporating the alcohol or by adding glycerin and alcoholic solutions of cane sugar. They are not necessarily purer than other soaps.

Laundry soaps usually contain rosin, or appreciable amounts of various chemicals which are beneficial when hard water is used. If these chemicals or free alkali is present in large amounts, the soap should not be used with silks or woolens.

Naphtha soaps contain a certain petroleum distillate, which is added because it can dissolve grease. This is a valuable ingredient in laundry soap if present in sufficient quantity to perform its intended function.

Medicated or antiseptic soaps are ordinary soaps to which have been added certain disinfectant agents such as carbolic acid, cresylic acid, and sodium perborate. Authorities say that soap itself is mildly antiseptic, and it is doubtful that the addition of these agents greatly increases this property.

Mechanics' soaps contain fine sand, pumice, or something similar to assist in removing dirt by its abrasive action.

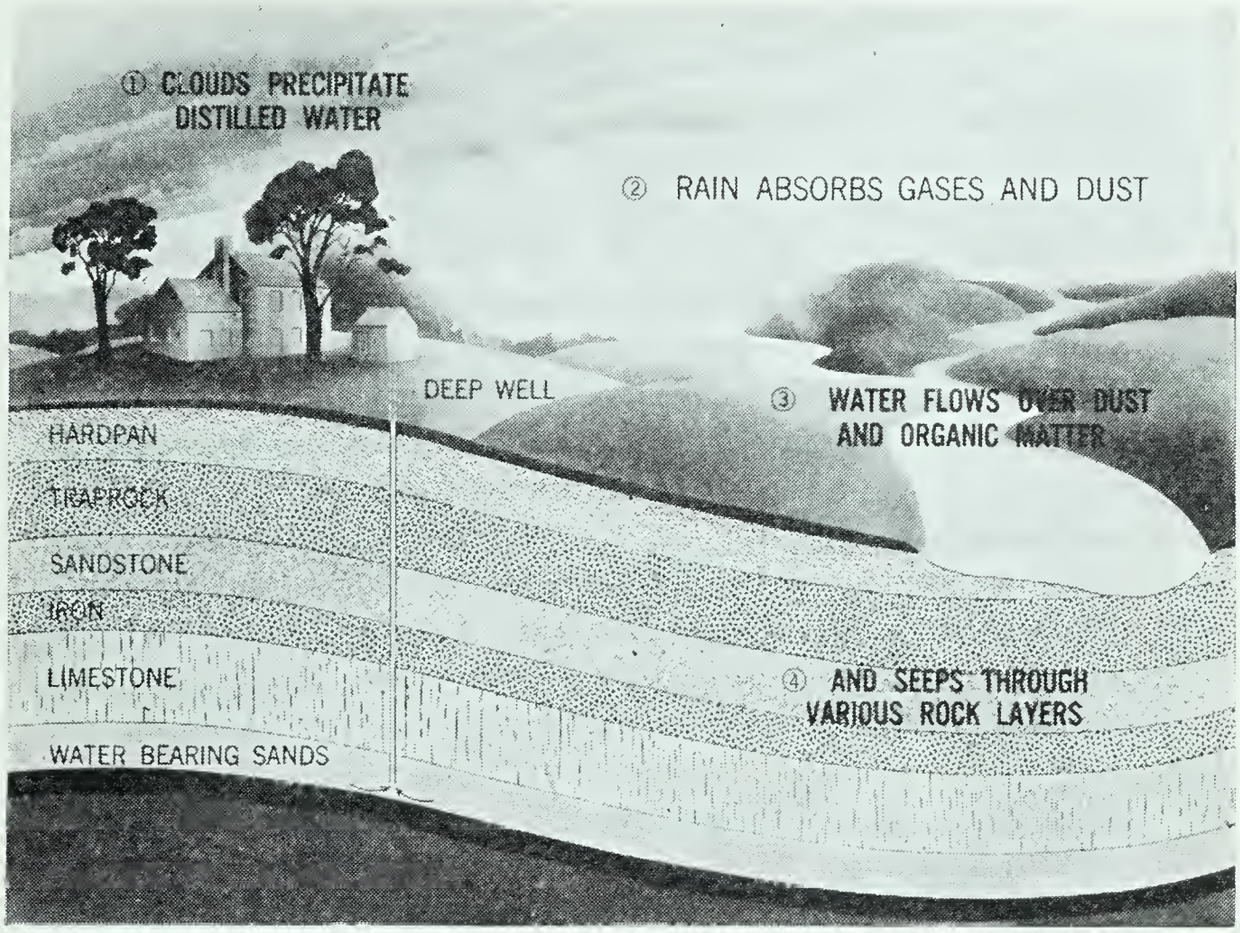
Soap chips or *flakes* are just what the name implies. *Soap powders,* however, never consist only of soap; in addition to finely powdered soap, they usually contain 50 per cent or more of some water softening agent, generally sodium carbonate. They are strongly alkaline.

Some advertisements would have us believe that soap is today's magic marvel. Shattered romances can be repaired, Hollywood beauty and glamour can be acquired, and we can even get our vitamins—through soap! So the advertisements would have us believe.

Although there are many varieties of soap, the differences among them are very slight, as we have seen, and they all serve but one function—namely, that of a solvent to cleanse the skin and remove dirt from fabrics. An unperfumed, white soap will do this job quite as well as one that is green or pink and has the odor of lilacs or lilies of the valley. Of course, there is no law against paying two or three times the price a pound for such soap if that is the kind you prefer. Soap should be neutral for nearly all purposes, but even the purest soap is more or less irritating to the skin, despite the many advertising claims to "gentle smoothness," "amazing mildness," and the like.

Hard water wastes soap and interferes with its cleansing action. As we have seen, ordinary soap is generally made by treating fats with sodium hydroxide; hence we speak of it as a "sodium" soap. "Hardness" is a property of water caused by the presence of certain dissolved minerals, which the water picked up during its passage through the earth as ground water. These minerals are principally compounds of calcium and magnesium.

When soap is used with hard water, chemical reactions take place which may be summarized as follows:



Courtesy The Permutit Company

Trace the "travels of water" in this illustration, and you will have a good idea of what is meant by the "water cycle." Which of the rock layers would contribute most to make the water hard?

sodium soap + calcium and magnesium minerals →
calcium and magnesium soaps + sodium compounds

Calcium and magnesium soaps are insoluble and form sticky, greasy curds in the water. This is very objectionable not only because additional soap must be used to produce suds, but also because the curd forms a film on laundered fabrics and on the walls of the receptacles which contain the water. The familiar "ring around the bathtub" is an example of the latter. This curd also clogs the pores and roughens the skin. Surely everyone knows how undesirable it is to wash the hair in hard water.

In recent years, chemists have given us some new cleansing agents made by treating certain kinds of alcohols with sulfuric or sulfonic acid. Therefore, they are not true soaps, but they form plentiful suds in either hard or soft water—that is why they are sometimes called "soapless soaps." When soft water or rain water is not available and hard water must be used, these products are a

boon, particularly for washing fine fabrics and shampooing the hair. As yet, they are expensive and have not proved their value for general laundry work.

Hard water can be softened chemically by the pint or by millions of gallons. Suds are essential to effective cleaning with soap, but suds will not form in hard water until the minerals that cause the hardness have been taken out of solution. Of course, an extra amount of soap can be used for this purpose, but there are several water-softening chemicals suitable for home use which are much less expensive than soap. Washing soda, ammonia water, borax, and trisodium phosphate are commonly used for this purpose. These substances react chemically with the minerals that cause hardness and turn them into insoluble materials which can no longer react with soap. Add just enough of the softener to remove the cause of hardness and to allow the soap to make a suds as soon as added. Avoid adding an excess as this makes the water increasingly alkaline.

A recent addition to the group of water-softening chemicals is sodium metaphosphate. It is unique in that it does not *precipitate* the troublesome minerals in hard water, but rather converts them into other substances which, although soluble, cannot react with soap. This product has been called "Calgon." Can you see why?

In many communities located in certain regions where the water is very hard, it is desired to soften the entire water supply before it passes into the city mains. Hard water used for industrial purposes also frequently needs to be softened; otherwise, "boiler-scale" deposits form, clog up hot-water pipes and boiler tubes, and greatly increase the amount of fuel needed to heat the water. There are two common methods by which water is softened in such large amounts—by treatment with lime and soda ash and by the zeolite process.

In softening water with lime and soda ash, the raw water is run into large basins. After an analysis to determine how much hardness the water contains, calculated amounts of lime (calcium hydroxide) and soda ash (sodium carbonate) are added to precipitate all of the objectionable minerals. The water is allowed to stand until the precipitate settles, and the clear, softened water is then drawn off; or, the water is filtered through rapid sand filters.

The zeolite process of softening water is used by industries, laundries, dye plants, small communities, and private dwellings. The hard water is passed through a tank containing zeolite, a complex natural or synthetic chemical which reacts with and removes the

minerals that cause hardness. This method yields water as soft as rain water. After a period of time, the zeolite becomes largely used up and must be renewed. This is done simply and inexpensively by running a solution of common salt into the tank of zeolite and allowing it to stand a while. Only salt is consumed, and the original charge of zeolite can be used for many years.

In removing spots and stains a few simple rules and principles should be followed. First, act quickly. Stains "set" on standing and become more difficult to remove. Second, work carefully and try the mildest treatment first. Quick action with an absorbent, such as starch, fuller's earth, talc, or even clean white blotting paper, is usually advisable on nearly all stains. Remember, however, that frequently the removal of spots and stains is really a job for an expert, and home treatment by an amateur may only make matters worse.

To remove spots and stains effectively and safely, you must know, first, what caused the stain and, second, the kind of fabric. If the fabric is not white, first try the stain-removal method on a hidden portion or a sample of the material and note its effect on the coloring. Stains are removed either by physical means, such as brushing, melting, and dissolving, or by chemical means. Nearly all stains common to the average household can be removed by proper use of the following agents:

hydrogen peroxide	carbon tetrachloride
benzene	oxalic acid
Javelle water	potassium permanganate

Hydrogen peroxide, Javelle water, potassium permanganate, and oxalic acid act on stains chemically, removing them usually by bleaching action. The strongest of these is Javelle water, a chlorine bleach made by combining bleaching powder and washing soda. Directions are given on the labels of bleaching-powder containers. Benzene and carbon tetrachloride are organic solvents for many stains, particularly paint and grease.

If these stain removers are kept on hand, they should all be put in bottles with odd shapes or stoppers, labeled correctly, and marked POISON. Remember that the vapors of benzene, naphtha, gasoline, and a few other solvents form explosive mixtures with air. Use such cleaners out-of-doors, and allow the garments to dry completely before taking them inside.

The table on page 482 summarizes the simpler methods of treating common spots and stains.

Stain	*Treatment*
Acids	Neutralize with ammonia water; rinse thoroughly.
Alkalies	Neutralize with weakened vinegar; rinse thoroughly.
Blood	If fresh, use soap and water or hydrogen peroxide; if dried, try Javelle water on cotton or linen but not on silk or wool.
Chewing gum, rubber, adhesive tape	Dissolve in carbon tetrachloride.
Cocoa, chocolate	If fresh, try boiling water, or sponge with chloroform; if long standing, try Javelle water on cotton or linen but not on silk or wool.
Coffee, tea	Try boiling water; on older stains use weak potassium permanganate solution followed by oxalic acid.
Fruit	If fresh, use boiling water except on wool; on older stains use potassium permanganate and oxalic acid.
Grass	Use denatured ethyl alcohol; "rubbing" alcohol will do.
Grease, oil	Use warm soapsuds, or dissolve in carbon tetrachloride or benzene.
Ink, ordinary	If fresh, treat with weak acid like oxalic or lemon juice; for older stains, prolonged bleaching (perhaps 7 or 8 days) is needed. Sulfurous acid bleaches. Javelle water on cotton or linen but not on silk or wool.
Iodine	Moisten with water and place on warm radiator or in sunlight. Soak in alcohol or "hypo" solution, or boil in starch solution.
Paint, varnish	Turpentine and carbon tetrachloride are effective for fresh paint spots; for varnish, use alcohol, turpentine, or benzene; for older stains, prolonged soaking in a suitable solvent is needed.
Paraffin, wax	Dissolve in benzene, ether, or kerosene; or place fabric between blotting paper and press with hot iron.
Rust	Treat with dilute acids, such as oxalic, tartaric, citric, lemon juice, or vinegar.
Tar	Try carbon tetrachloride or turpentine; then wash with soap and water.

Food for the clothes moth costs the consumer many millions of dollars a year. Furs, rugs, clothing, and upholstery form the chief items of its diet. The actual damage occurs after the eggs hatch when the larvae begin to feed upon the materials at hand. This stage of the life cycle of the moth may last several months, and tremendous damage may be done. The following measures are recommended to avoid the ravages of this pest:

Air and inspect clothing and furs frequently. Brush and sun them out-of-doors on bright, windy days.

Wash or dry-clean fabrics frequently to kill eggs and larvae.

Store garments, furs, and bedding in hermetically sealed containers after thorough cleaning, brushing, and airing. It is well to place inside the container a moth-repellent, such as moth balls or flakes, or paradichlorobenzene.

The U. S. Department of Agriculture Leaflet Number 145, *Clothes Moths,* gives specific information regarding the effect of temperature on moths. They are killed within two days at 0° F. and in a short time at a temperature between 125—130° F. Liquid sprays containing stomach poisons for moths are effective if properly applied. Every square inch of fabric or fur must be treated if this method of moth control is to be successful. So-called "moth-proofed" fabrics which are on the market today contain chemicals which give protection for a period of time, but none has yet been developed which is not removed by frequent laundering or dry cleaning.

Exercises for Problem Study and Review

1. What are the chief agencies which cause corrosion of metals? What four methods are used to prevent this corrosion? What principle underlies each method of prevention?
2. When are metals "self-protective"? Why is galvanizing such an effective method of protecting iron?
3. Outline the various methods of applying protective metallic coatings to other metals and give an illustration where possible.
4. Describe a satisfactory method of cleaning and polishing each of the metals likely to be found in the household. What general precautions are necessary?
5. What are the general procedures for guarding against the destruction of wooden structures by rot? By termites?
6. Give examples of pigments, vehicles, thinners, and reinforcing agents used in paints. What is the function of each?
7. What is a lacquer? A plasticizer? What are the special advantages obtained by substituting lacquers for ordinary paints?

8. Explain the composition of varnishes. What is the action of a drier in a paint or varnish?

9. List the precautions that should be followed when using paints and paint removers.

10. What are the most common mistakes likely to be made in the home laundry?

11. How is soap made? What are hard soaps? Soft soaps? Framed soaps? Milled soaps? Glycerin?

12. Explain how the following are made: floating soap, transparent soap, laundry soap, naphtha soap, antiseptic soap, mechanics' soap, soap powders.

13. When is water hard? Explain how hardness in water affects the action of soap.

14. The chemist has solved the problem of hardness in water both by modifying the soap and by softening the water. Explain the methods employed and the relative merits of each.

15. In what two ways do stain removers work? What precautions should be taken when using or storing them? Which removers do you think it advisable to have on hand in the home?

16. When moths are seen flying about in the home, it is logical to expect that some damage has already been done. Explain.

17. What are the best methods of protecting fabrics against destruction by moths?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. Would there be any advantage in buying unbleached muslin or linen for use in making sheets and pillow cases and then bleaching them by frequent washing, airing, and sunning? Explain your answer.

2. A man is preparing to lay a concrete walk from his house to the garage. Make a list of rules that he should follow in order to obtain the best results.

3. A housewife has purchased a new enameled kitchen range. What precautions should she take to preserve the finish?

4. Unpainted girders, fences, and other exposed structural iron rusts rapidly, but the iron grates of a furnace last for many years without rusting greatly. How do you account for this difference?

5. Copper companies are now using low-grade ores that they threw away years ago. They treat the ore with sulfuric acid and run the solution into vats to which they add old tin cans. Explain the science ideas underlying this method of recovery.

6. Why are magnesium, tin, and manganese called strategic metals? Give illustrations in your answer. Are there any other strategic metals?

7. Wood is a better conductor of heat than air. However, heat escapes through a hollow wall faster than through a similar wall filled with sawdust. Explain.

8. In your town is it cheaper in the long run to rent or to buy a home? Gather sufficient data upon which to base your answer.

9. A student filled three bottles completely, one with wet lime-sand mortar, one with wet cement-sand mortar, the third with wet plaster-of-Paris paste. The bottles were then tightly capped. Will their contents harden? Explain.

10. Defend the statement that has been made in reference to steel, "We could give up any other metal with less effect upon our civilization."

11. On the basis of scientific principles involved, make a comparison of summer and winter wearing apparel in respect to color, ability to transfer heat, and ability to transfer moisture.

12. Plumbers' solder is a mixture of lead, the melting point of which is 327.5° C., and tin, which melts at 232° C. Predict what the melting point of this alloy would be. Verify your prediction and account for the true melting point.

13. Would you expect most metal polishes to be acidic or basic? Explain.

UNIT WORD LIST

quicklime
slaked lime
gypsum
alabaster
by-product
clinker
Keene's cement
glaze
metallurgy
ore
oxide
flotation
gravity separation
compound
oxidation
reduction
flux
slag
charge
annealing
ingot
electrolysis
alloy
ferrous
tempering
casehardened
sizing
vulcanization
hydrogenation
antichlor
mercerizing
Sanforizing
mordant
chrome tanned
kiln
thermoplastic
thermosetting
Celanese
collodion
viscose
corrosion
galvanize
sherardizing
calorizing
abrasive
paint vehicle
varnish drier
pyroxylin
precipitate

INTERESTING THINGS TO DO

1. Make a collection of rocks, minerals, and other materials from the crust of the earth which are used in construction.

2. Prepare an exhibit of commercial insulating materials.

3. Make a photographic record of stages in the construction of a building. Under each write a caption to call attention to the application of scientific principles.

4. Make a collection of asbestos products.

5. Mount samples of the different types of leather upon a poster. Include also a summary of the important facts about each.

6. Collect samples of common metals which have undergone considerable corrosion. Learn the chemistry of what happened to each metal.

7. Make a flow chart of the Solvay process for making sodium carbonate.

8. Report on the methods used by the National Bureau of Standards, consumer organizations, and other agencies which test consumer goods.

9. Explain to the class how blueprints are made and used. Illustrate your talk with sample blueprints.

10. Prepare a chart or poster of various types of weaves, including a description and an example of each. Obtain samples of fabrics from a department store. Explain your poster and show your samples to the class.

11. Consult authoritative sources and prepare a list of suggested questions and rules to serve as guides in purchasing such textiles and fabrics as clothing, bedding, towels, and linens. Explain your suggestions to the class.

12. Make a list of some of the more popular uses of the "big four" fibers, naming the property or properties which lead to each use.

13. Plan the construction of an average-size family dwelling. (1) Make a list of the major problems arising with respect to the selection of construction materials, such as: (a) What kind of foundation shall be used? (b) What kind of roofing material shall be selected? (c) Shall galvanized-iron or brass pipe be used? (2) Make a list of several construction materials available for use in each of the above cases. (3) Make a list of the materials you would select for use in each case if cost were not a factor to be considered. (4) Make a revised list of the materials you would use in each case if the cost of the dwelling were not to exceed $6,000. (5) Select one instance in which your lists in (3) and (4) differ and one instance in which they agree, and point out clearly the science back of your choice.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. Recovery of construction materials from the ocean.
2. Prince Ruppert's teardrops and Bologna bottles.
3. How braces, arches, and buttresses are used to secure strength in buildings.
4. The construction of foundations for skyscrapers.
5. How coal-tar dyes are made.
6. How linoleum is made.
7. Methods used to make plastics.
8. How tung oil, linseed oil, and other oils used in paints are obtained.
9. The symptoms and treatment of lead poisoning.
10. Life history of the clothes moth.
11. The history of soapmaking.
12. How linen thread is made.
13. Dyes obtained from plants and animals.
14. What a widely known consumer organization says are the best buys in radios, shoes, fountain pens, and other common articles.
15. Whether or not a subscription to a consumers' organization which publishes information about articles which they have examined and tested is a good investment for your family.
16. Charles Goodyear's investigations on rubber.
17. The building code for your community. Report on the types of items covered.
18. The zoning regulations of your community. What are the reasons for such planning?

INTERESTING BOOKS TO READ

Beery, Pauline G., *Stuff: The Story of Materials in the Service of Man.* D. Appleton-Century Company, New York, 1930. Nontechnical and very readable.

Carver, Thomas N., Woolman, Mary S., and McGowan, Ellen B., *Textile Problems for the Consumer.* The Macmillan Company, New York, 1935. An authoritative presentation of the economics of textile consumption. Practical suggestions on selection and care are given.

Conklin, Groff, *All About Houses.* Julian Messner, Incorporated, New York, 1939. The story of the building of a house. Illustrated with 369 photographs. Valuable from the consumer point of view.

Hibben, Thomas, *The Sons of Vulcan.* J. B. Lippincott Company, Philadelphia, 1940. A readable and valuable book which surveys the changes that have taken place in the metal industry from the days of the primitives to the master craftsmen of today.

Trilling, Mabel B., Eberhart, E. K., and Nicholas, Florence W., *When You Buy.* J. B. Lippincott Company, Chicago, 1938. A high school text devoted to helping students recognize and solve the problems of consumer buying.

Wilhelm, Donald, *The Book of the Metals.* Harper and Brothers, New York, 1932. Simply told stories of the metals, their mining, making, alloying, and amazing uses. Nontechnical but authoritative.

eflected Light Reveals Secrets

of Ill. Scientists Report New Method of Measuring Contents of Solids

MILWAUKEE—A new scientific ol for industry, which tells un- en properties and secrets of rocks d minerals by the way they re- ct light, was announced to the erican Association for the Ad- ncement of Science here today. The light tells the amount of heat ich can be had from coal so that

LTRA-VIOLET RAYS CUT CLOTH LOSSES

imination of Mold Will Save Textile Field Many Millions, Says Bacteriologist

VE PLANTS USE PROCESS

gineers Test Commercial Applications to Determine Greatest Effectiveness

Ultraviolet Rays Used to Prevent Seafood Spoiling

WASHINGTON (AP) — A dis- overy that treatment with ltraviolet rays will help pre- ent seafood from spoiling was eported yesterday by the Bu- au of Fisheries.

Health Officers See Lamp Kill Bacteria on Drinking Glasses

New Jersey health officers, meeting today in Nutley, were given a demonstration of what is hoped will water, and that where glasses are in constant use contamination is increased by accumulation

X-Rays Record Metal Strength In Dot Pictures

New Photograph Technique Also Used in Biological Examination of Tissues

UNIT SEVEN

LIGHT AND RADIATIONS

SHOW MOVIES OF CRUDE OIL DEVELOPMENT

'Black Light' Enlisted for Traffic Work

Ultraviolet light—that mysterious and eerie substance known as 'black light"—is another scientific development ready to step in on a moment's notice if possible blackouts should threaten to disrupt vital automobile night traffic in American cities.

Atom-Smasher's Rays Said to Aid Cancer Victims

San Francisco, Dec: 3.—(UP) — An atom - smashing cyclotron at the University of

Experts Hunt for Needle--- of Radium

The proverbial search for a needle in a haystack had its coun-

Camera 'Shoots' 925 Naval Men In 174 Minutes

Marching single file before a high-speed camera, 875 midshipmen of the United States Naval Reserve school at Northwestern University and 50 service employees were photographed yesterday in 174 minutes.

'Electric Eye' Car Counters Bought

Bismarck, N. D., April 29.—(AP)—Automatic traffic recorders, equipped with an "electric eye" to daily count hundreds of motor vehicles

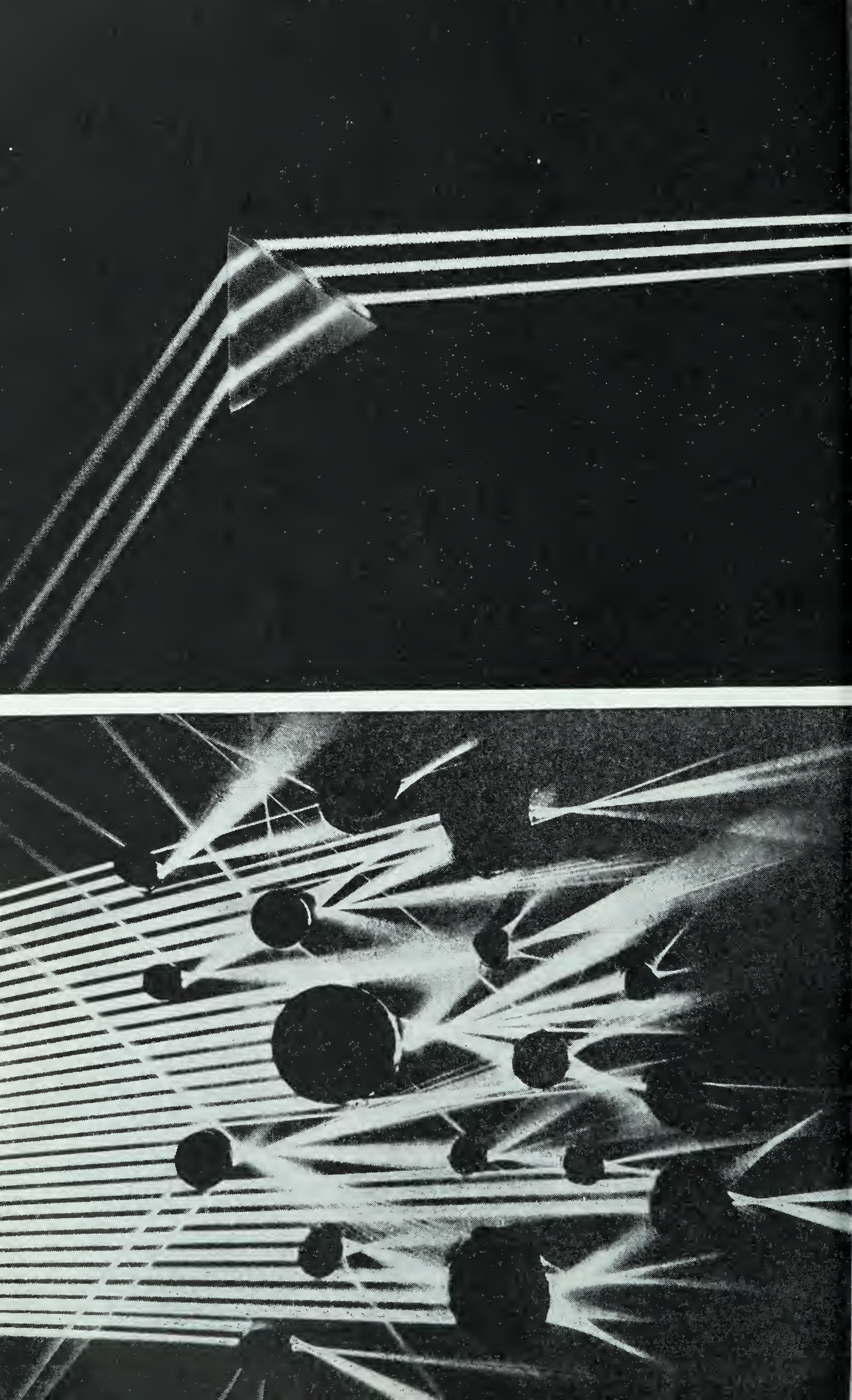
lasses Soon to Be a Must or Well-Dressed Student

utrition Film o Aid Defense

lming a documentary motion ure on nutrition has been ed in Hollywood, according to

Safeguard Your Eyes

Great progress has been made in



Unit Seven

LIGHT AND RADIATIONS

The lighted portion of the earth's surface is constantly receiving countless numbers of tiny light waves which stream to it through space at the greatest speed known. Although the energy reaching our planet from the sun is only about one two-billionth of the total amount sent out in all directions by that body, it is, nevertheless, enough to make life on the earth possible and to determine to a large extent the nature of that life. It regulates the temperature of the earth's crust, supplies the energy used by plants in making food, and brings us light for seeing.

In the absence of light, even a perfect eye is blind; in the presence of light, most eyes can see. When we do see, we see color, form, brightness, and, perhaps, motion. How well we see depends upon two things—(1) the quality and quantity of the light; (2) the ability of the eye to respond to the light that strikes it. Like the sun certain objects may serve as light sources by transforming some other form of energy into light. These are described as *luminous.* Most things that we see, however, simply reflect light that falls upon them. They are said to be *illuminated.* The important consideration as far as sight is concerned is that we see only those things from which rays of light come to our eyes.

Exactly what is light? How do our eyes use light to produce sight? It may be disappointing to learn that scientists cannot give an entirely satisfactory answer to either of these two questions. However, we must not fail to note that a great deal is understood about both. Much of our understanding of light is in terms of theory. If we judge the theory in terms of the evidence supporting it and in terms of its usefulness, we will undoubtedly feel that scientists have gone a long way toward answering the questions raised above. The importance of these questions concerning light and sight is evident when we realize that man gets more than three-fourths of all his knowledge through his eyes.

In this unit, we shall investigate how man at the present time is making adjustments to problems of producing, controlling, and using light. These problems are age-old, but we are constantly gaining new knowledge which enables us to work out better solutions.

Photos courtesy General Motors Corporation

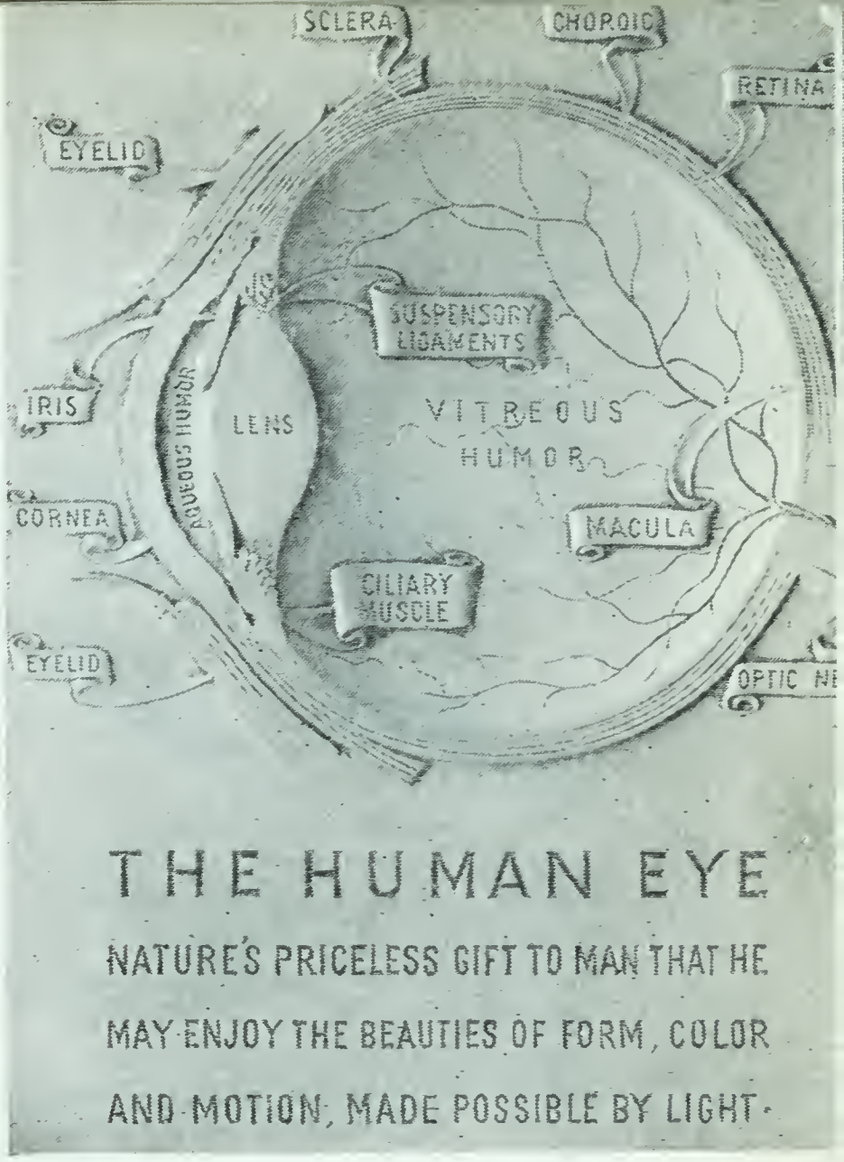
Problem 1: How do we see?

Seeing is a complex process. It requires an object, an eye, and light. When we see, we see light; and when we see light, we see color. How much less attractive this world would be without color! The psychological effects that colors have upon us are indicated by our reference to the cool, refreshing green of the forest, the cold blue of the ocean, or the warm, red glow of the fireplace. Some people have faulty color vision and do not sense colors in the same way as do most of us. Why do more than 5 per cent of the population see colors differently than other people see them? Before we can answer this question and other related ones, we need to consider carefully the two factors which enable us to see objects—the eye and light itself.

• FROM LIGHT TO SIGHT

The eye is the sense organ which serves as the window of the brain. Some of the structures and parts of the human eye are shown in the diagram. When light from some object or scene enters the eye, the rays are bent by the cornea and the lens in such a way that a tiny, upside-down image is formed on the retina. Any lens system that makes light behave in this manner is called a *converging* one, because it bends the light rays so that they come together after passing through. The retina is the sensitive film of the eye and contains the nerve endings known as *rods* and *cones*. When the image forms on the retina, in a manner not completely understood, the rods and cones are stimulated and send nerve impulses over the optic nerve. We do not experience the sensation of seeing until the photographic picture produced by the eye has been telegraphed to the brain. When the nerve message is received in the brain, it is interpreted as being right side up, and we "see."

When we use a camera to photograph near-by and distant objects, we must change the focus accordingly. Similarly, the eye must change its focus for near-by and distant seeing. The change in focus is usually accomplished in a camera by moving the lens nearer to or farther from the film. In the eye, focusing is done by altering the thickness of the lens. If you have ever examined magnifying or "burning" lenses, you may have noticed that the thicker the lens, the shorter its focus—that is, the closer it must be held to the object to be magnified if you are to see clearly. In the case of the eye, suspensory ligaments hold the lens for far vision;

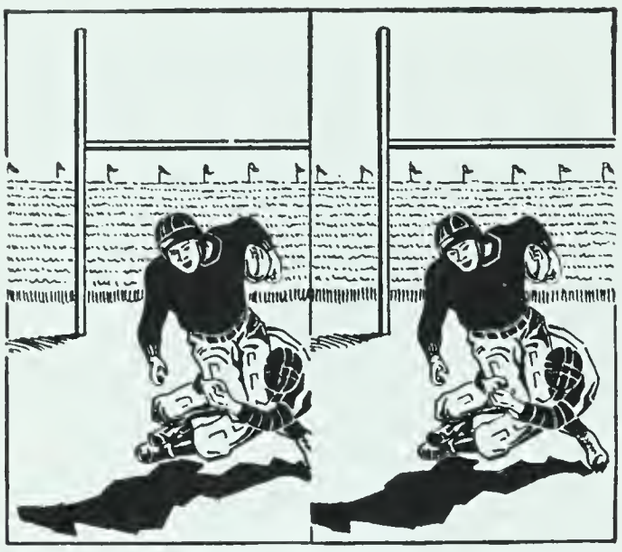


Courtesy Bausch and Lomb Optical Company

Consult your biology teacher, and learn the function of each part of the human eye.

for close work, ciliary muscles contract and relieve this tension—otherwise the image would not form sharply on the retina and vision would be blurred. While you are reading this book, look out the window at a distant scene for a minute or so and then come back quickly to reading again. Do your eyes require a short time to adjust to the change in distance? This ability of the eyes to change their focal length is called *accommodation*. As people get older, the eyes lose this ability to some extent.

Our recognition of depth in scenes about us is due to the fact that we have two eyes. If the Cyclopes, the one-eyed giants of Homer, had been more than myths, they would have seen a slightly different world than we two-eyed humans see. Cover one of your eyes and look about you with the other one. Notice the flatness and lack of depth which disappears when you look normally with both eyes. Since the eyes are a few inches apart, each one really forms a slightly different image of a scene than the other. It is the combining of these two images in the brain which gives us a better idea of relative distances and of depth. An ordinary photograph has the same flatness as a view seen with one eye because it was taken with a camera having a single lens system. The stereoscope illustrates how it is possible to get the impression of depth when viewing specially made photographs. In the stereoscope you look at two pictures at the same time; they are mounted beside each other on a card, and if you look at them carefully beforehand, you will see that the two pictures are nearly but not quite identical. They are pictures that have been photographed at the same time with camera lenses separated by a distance about the same as that between our two eyes. When the two pictures are viewed simultaneously with the stereoscope, each eye forms much the same



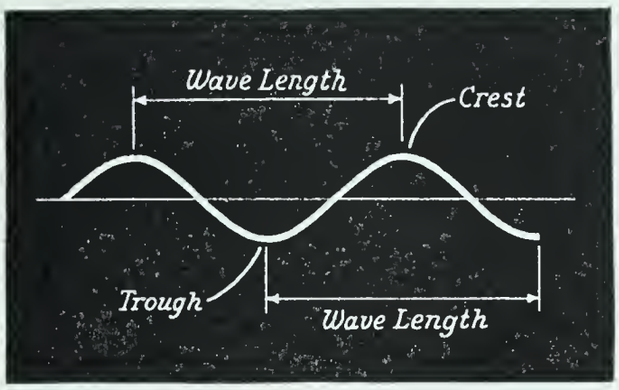
Binocular vision adds the third dimension to our view of the world. Here is a way to obtain the illusion of depth in this illustration: Focus your eyes on some distant object. Hold this book about fifteen inches from your eyes and move the illustration into your line of vision without changing the focus of your eyes. When you succeed in seeing three pictures, the football players will seem to stand out very clearly in the center one.

image that it would if it were viewing the real scene, instead of photographs of it. The way in which the objects stand out in the scene is especially striking because we are not used to seeing depth in photographs. It is *binocular vision,* then, that adds the third dimension to our view of the world.

The muscles which turn the eyes inward so that they look at the same point are called *converging* muscles. The amount of stress on these converging muscles indicates to us the distance of objects from our eyes. The energy used in convergence is tremendous for close work and is an important cause of eyestrain—made worse if optical errors are not corrected as these muscles try to do the work of accommodation as well as convergence.

• FROM WAVE LENGTHS TO COLOR

We have said that when we see light we see color. Color does not exist except in the presence of light, and the physical basis for color lies in the light itself. Let us examine this relationship between light and color. According to the wave theory of light, light of each wave length represents a single color; waves differing in length represent different colors. Light really travels in trains of wave lengths. As illustrated, a wave length is the distance from one crest to the corresponding point on the next crest. When a complete assortment of wave lengths strikes our eyes it produces the effect which we call white light, such as that of the sun. Black and white are really not colors. Black is due to the absence of light, whereas white is due to a proper combination of light of all colors. Thus, according to this theory, if an object tends to send no light to the eye, it is black; if, as eithera luminous or an illuminated object, it does send rays to the eye, it appears white, gray, or colored. In white light all wave lengths are present, and also



Wave length is the distance between a given point on one wave and the corresponding point on the next wave.

they are present in the same amounts.

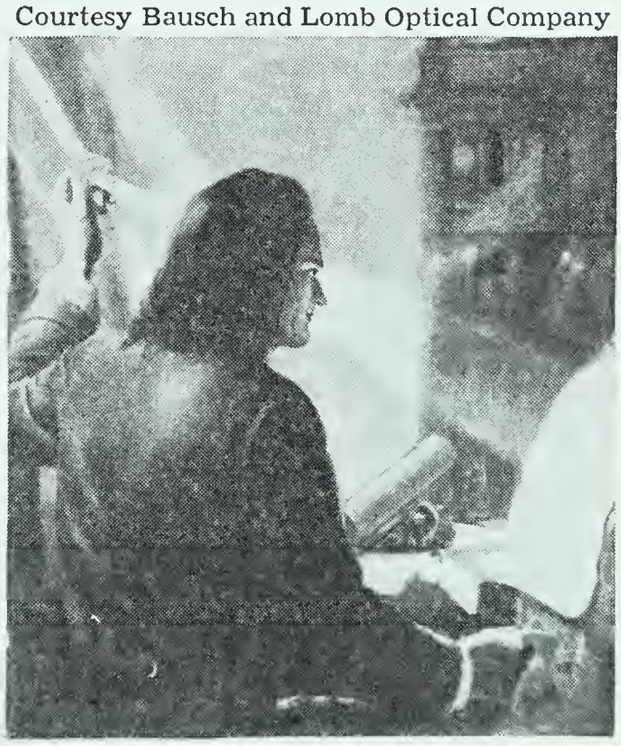
All solid bodies give off visible light when heated sufficiently. Burning coal and the incandescent lamp illustrate this fact. As the blacksmith heats an iron in his forge, we say it becomes first red-hot and finally white-hot. In other words, the number of wave lengths emitted increases as the temperature is raised, and the proportion of wave lengths also shifts. First, reds predominate. Then, orange, yellow, green, etc. Finally, the assortment is complex enough to produce white light. The red color of the neon sign and the yellow color of the sodium-vapor street lamp indicate that these glowing gases do not give off so complex a mixture of radiations as does the ordinary incandescent lamp with its nearly white light. Our sun broadcasts an even greater assortment of wave lengths, many of which, as we shall later see, do not affect the eye at all.

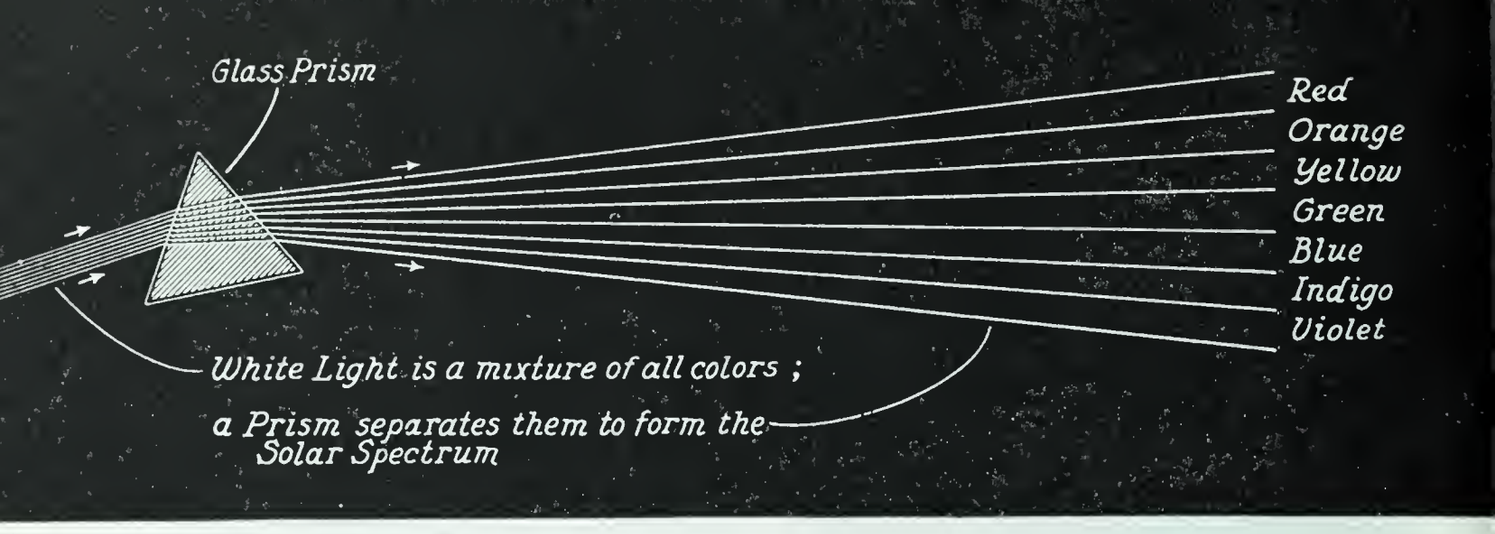
It is a simple task to determine just how complex white light is. If you have ever seen a rainbow, you have observed white sunlight separated by raindrops into the colors composing it. Sir Isaac Newton discovered that we can easily duplicate this separation by means of a glass prism. His report of the experiment is as follows:

"In the year 1666 (at which time I applied myself to the grinding of optick glasses of other figures than spherical) I procured me a triangular glass prism, to try therewith the celebrated phenomena of colours. And in order thereto, having darkened my chamber, and made a small hole in my window sheets, to let in a con-

Through his extensive experiments with light, Sir Isaac Newton (1642-1727) became one of the founders of modern optical science.

Courtesy Bausch and Lomb Optical Company



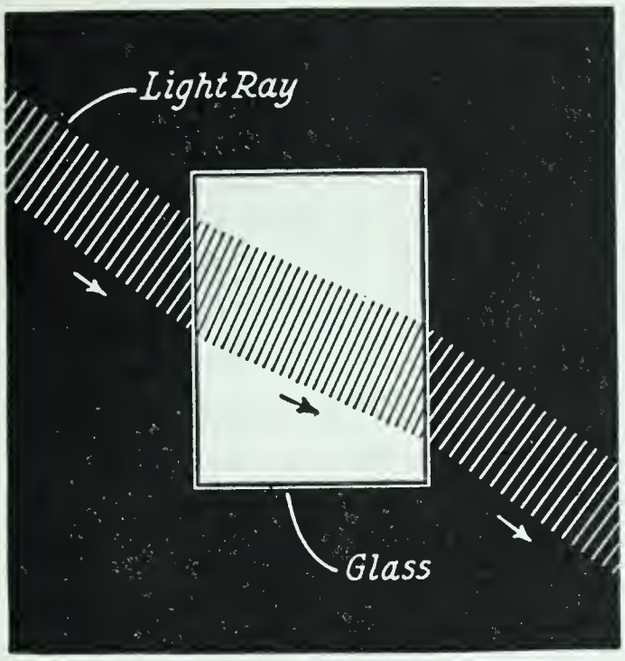


venient quantity of the sun's light, I placed my prism at its entrance, that it might thereby be refracted to the opposite wall. It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby."

The diagram shows a beam of sunlight passing obliquely from air into a glass prism. Although light travels in straight lines in a given medium such as air, it is bent when it passes from one medium to another where it travels at a different speed. Light does not travel as fast in glass or water as it does in air. Such bending of light rays as they pass from one medium to another is called *refraction.* The wave lengths which our eyes interpret as red are bent or refracted the least upon passing from air into glass, whereas the refraction becomes greater as we progress from the wave lengths for red to those for orange, yellow, green, blue, indigo, and violet. Whenever sunlight is passed through a prism in this fashion this same array of colors, called the *solar spectrum,* is obtained if a screen is placed behind the prism. By means of a second prism, it is possible to mix the seven colors obtained from the sun's rays by refraction and reproduce white light. How might this be done?

The refracting medium does not have to be glass. Some other transparent material in which light travels at a different rate than it does in air will do. At sunset, for example, when the sun's rays pass obliquely from the emptiness of space into the dust-laden atmosphere, there is a similar bending. Since the red rays are bent the least, they come to us in greater proportion than the others, making red the outstanding color of a beautiful sunset. During the day the sky is blue, since these rays are refracted and dispersed the most.

The explanation for refraction is simplified by a glance at the diagram on page 497. The upper parallel lines represent an advancing wave front which is about to pass from air into glass. Since the ray is not perpendicular to the surface of the glass, part of its front enters the glass before the rest. It is slowed up because light travels more slowly in glass than in air. The part of the wave

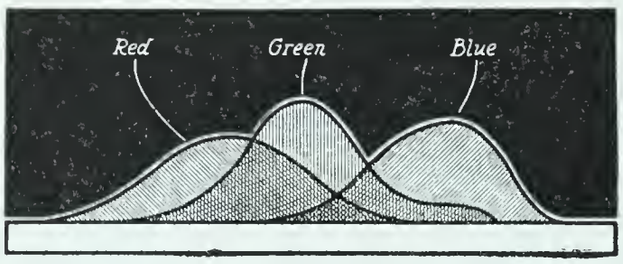


The direction of a ray of light changes as it passes from one kind of transparent material into another—as from air into glass and out again.

front still in air therefore travels forward faster than the part in the glass. This causes a bending of the ray as it passes from the one medium into the other. When the entire wave front has entered into the glass, there is no further bending, and the ray then advances uniformly in the new direction. Can you explain the bending shown in the diagram where the ray passes again from glass into air? A similar change of direction could happen to a column of soldiers who while marching upon a hard surface came upon soft ground or other impediment in such a way that one side of the column's front was slowed up before the other. If the impeding area were rectangular the column would bend again as it emerged and would proceed in a direction parallel to the original direction but not in the same straight line.

At this point you might well begin to wonder how it is possible for some objects to appear blue, some red, and others green when white light falls upon all of them. Since nonluminous objects are seen by reflected light, it seems logical to conclude that *colored objects reflect only part of the white light which they receive.* If something reflects only the radiations which the brain interprets as blue, then we recognize it as a blue object; if only red wave lengths are reflected, the object is red; the same is true for all other colors. But what happens to the other wave lengths of the white light which are not reflected? According to the law of conservation of matter and energy, they are not destroyed and must be accounted for. The answer is—they are absorbed and transformed into heat or used to cause chemical change. Nearly all of the sunlight which reaches the earth is finally transformed into heat. In this way the temperature of the earth's crust is kept within the limits where man and other forms of life as we know it can survive.

But can this generalization—that the color of an illuminated object depends upon the nature of the rays which it reflects—be tested experimentally? One of the best ways to test the truth of an



The retina is believed to contain three kinds of color receptors, which overlap somewhat as indicated by the diagram. Color is seen whenever they are stimulated unequally; equal stimulation produces the sensation we call white.

assumption is to make a prediction of something else that would have to follow if the original hypothesis were true—some prediction that can be tested in the laboratory. In this case, we might ask what color an object which is red in white light would be if it were placed in light which contained no red rays. If there were no red rays falling upon the object, there would be no light which it could reflect. According to this theory, when an object reflects no light it should appear black. Experiment confirms this prediction that an object which is pure red in white light appears black in light which contains no red rays. In blue light, a red object becomes a black one. Theater-goers are not always aware that a change in setting, as from spring to winter, is sometimes brought about simply by changing the color of the light directed upon a properly designed backdrop painted with the correct selection of colors to produce the desired effect.

Colored glass tends to absorb all light rays except those corresponding to its own color. These pass through it. Blue light, for example, can be obtained by passing sunlight through a blue glass.

A widely accepted theory has been advanced to explain how we see different colors. According to this theory, in the retina of each eye are three types of nerve cells for registering color—one type for red, one for green, and one for blue. Of course, more than one of the three types can be stimulated at one time. The color seen depends upon what combination of color receptors is stimulated by the light reaching the eye. The relative proportion of each type of nerve affected, as well as the number of types, is important in determining the shading of color seen. White light stimulates all three kinds of receptors equally. Color is seen whenever the three kinds of receptors are stimulated unequally. The fact that all of the colors of colored motion pictures can be produced from red, green, and blue serves to make the explanation of this theory more plausible.

The theory has a very obvious explanation for color blindness. If one's eyes lacked any of the three types of color receptors, cer-

tain colors would not register properly and would simply appear shaded or gray. Rarely are all three missing, but in such extreme cases the eye recognizes no color, and objects appear in varying degrees of light and dark. About 8 per cent of all men and 5 per cent of all women are born color blind, and unfortunately there is no cure for this defect. John Dalton, the Englishman to whom we are indebted for the atomic theory, seems to have been the first to realize that some persons do not interpret color in the same manner as do most of us. In fact his discovery resulted from his being one of the unfortunates. For a while this quiet and reserved schoolmaster was perplexed when his fellow Quakers chided him for his lack of modesty in his dress. Later on it occurred to him that perhaps his "green" stockings were scarlet as his neighbors insisted. Color blindness may cause humorous situations, but the inability to recognize certain colors is really a serious handicap. Some states give a special test to those applying for licenses to operate automobiles, in order to make sure that those granted licenses can recognize red and green easily. The wisdom of this precaution for the safety of everyone on roads where traffic is regulated by signals of these colors is obvious.

• COLOR BY ADDITION, SUBTRACTION, AND CANCELLATION

There are three primary colors with which we can produce all other possible colors. The three primaries of light are red, green, and blue. There is, however, a great difference in the results obtained when colored lights are mixed and when colored pigments are mixed.

When the light waves for more than one color are added together, we see only a single color. Yellow and blue light can thus be mixed to produce white. In fact, there are a number of combinations of colors which produce white light when added together. Any two colors of light which together cause the sensation of white are called *complementary colors.* Complementary colors can be mixed by rapidly rotating them on the color disk. Then the brain interprets the mixed sensations as a single color. As stated previously, any desired color can be obtained by the proper mixing of primary colors. The single effect produced on the eye is due to their combination.

The mixing of paint pigments is a subtraction rather than an addition process and different results are obtained. When yellow and blue *lights* are added together, white is obtained; when yellow

and blue *paints* are mixed, the resulting paint is green. A knowledge of what each pigment absorbs (subtracts) from the white light falling upon it gives the clue as to the reason why green is obtained. Yellow pigment absorbs all of the white light which falls upon it except red, yellow, and green; blue pigment absorbs all except blue and green. Consequently, when the two are mixed, green is the only color not absorbed by either of them. Blue is still reflected by "blue" pigment and yellow by the "yellow" pigment—but green is reflected by both and becomes dominant.

The absorption of light by pigments is something to be considered when selecting colors for decorating rooms. The absorption, and hence the reflecting abilities of paints, varies greatly with respect to color. The cost of adequate artificial illumination will depend to some extent upon the colors of the walls and ceilings. For such reasons, color becomes a very important consideration. However, no amount of paint of any particular color can insure good lighting in an interior which is poorly supplied with either natural or artificial illumination. A comparison of the light-reflecting power of variously colored paints is shown below.

Color	*Light-reflecting power*
White (new)	75%–85%
Cream	60%–80%
Ivory	70%–80%
Green (light)	45%–75%
Yellow	60%–75%
Buff	50%–70%
Blue	35%–60%
Pink	35%–60%
Gray	10%–65%
Tan (dark)	30%–55%
Red (dark)	10%–30%
Green (dark)	10%–25%

The many colors of nature result from a variety of causes. Many colors such as those of trees and shrubs are caused by pigments. The leaves change from green to yellow and orange as autumn replaces summer because yellow and orange pigments replace the green ones. The white color of clouds is due to reflection; the beautiful colors of the sky in the morning and evening result chiefly from refraction.

Colors may also be produced by *interference.* Just as it is possible for two sound waves to interfere with each other and produce

silence or to reinforce each other and produce a louder sound, it is possible for light to produce various effects, such as a series of light and dark bands or a variety of colors. The varying thickness of oil films and soap bubbles is responsible for the interference which results in the array of colors frequently seen on them. The plumage of birds, very brilliant in the case of the peacock, is due to interference at the surface of the feather rather than to the presence of pigment as one might suppose.

Contrasts in brightness or color help us to see things more clearly. Hence—if tasks are naturally dark and cannot be changed, which is usually the case, more light has to be used to raise the brightness. This book, like most others, has been printed with black ink on white paper to make the contrast as great as possible.

Protective coloration owes its effectiveness largely to a lack of contrast. A green insect on a green leaf or a polar bear against a background of snow is difficult to see from a distance even when there is plenty of light. Indeed, it is the contrast of the bear's shadow with the snow that is most likely to betray his presence.

The complementary colors are, as a general rule, the pairs of colors which give the greatest contrast. With red on green, the red appears redder and the green seems greener than when each is placed on some other color. Yellow and blue likewise intensify each other. If you have not done so already, take notice of the frequency with which complementary colors are used to attract attention to advertisements in streetcars, on billboards, and in other displays.

Exercises for Problem Study and Review

1. What conditions are necessary for seeing an object?
2. What is the difference between a luminous object and an illuminated one?
3. Why is sight often called man's most important sense?
4. How do we see depth in the scenes about us?
5. What is "white" light? Colored light?
6. What is the solar spectrum?
7. Explain how colors of the spectrum are produced when light is refracted?
8. Explain why objects are called color mirrors.
9. How could you make a red object appear black?
10. In what respect is a piece of colored glass a color trap?
11. Industry chooses color combinations which promote safety and efficiency. Explain.
12. What becomes of the sunlight which strikes the earth?

13. What are primary colors? What are complementary colors?
14. What factors should be considered when choosing paints for interior decorating?
15. Why is color blindness a more serious defect in modern society than it was in primitive society?
16. Are colors produced by causes other than the presence of pigments? Explain.
17. List five instances where you have seen contrast in color or brightness used to get certain effects.

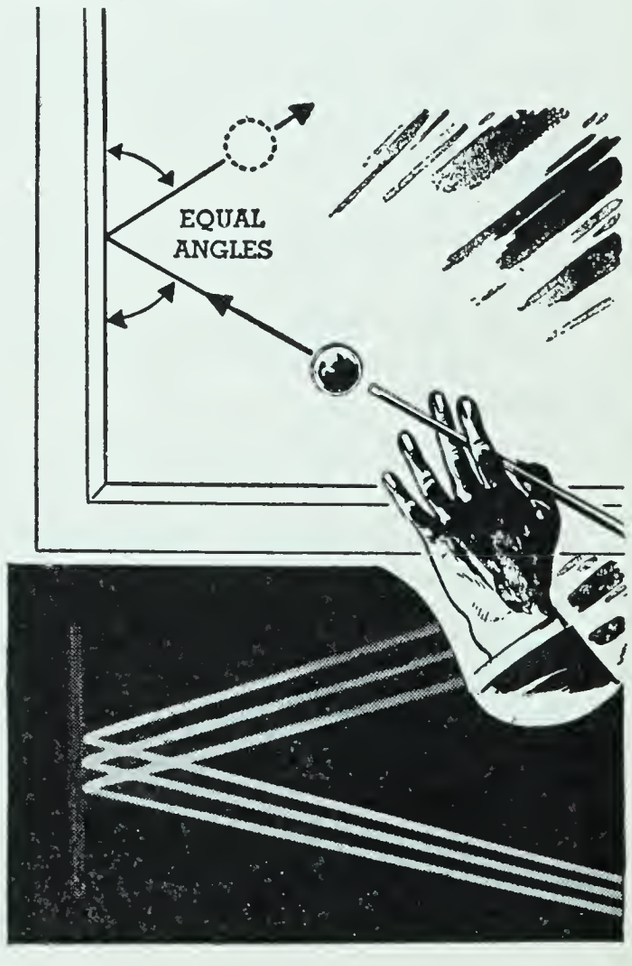
Problem 2: How do we control light?

Imagine the thrill of being able to say, "I can show you a new world, a world that has existed since the beginning of time, a world that surrounds us, that is in every place at which we look, yet a world that no man has ever seen before." This honor fell to Anton van Leeuwenhoek at Delft, Holland, less than three centuries ago (1675) as he studied the world of tiny plants and animals which could be seen only with his new instrument—the microscope. Galileo must have experienced similar joy when in 1609 he first turned his "optik tube," or telescope, toward the heavens to see the universe revealed as no man had before seen it. As Americans, we are proud of the fact that Benjamin Franklin invented bifocal spectacle lenses worn by millions to improve their vision.

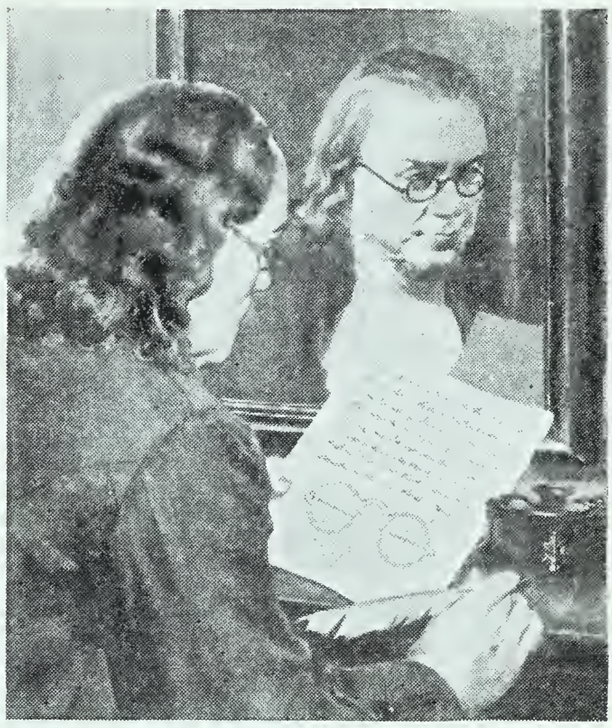
A study of these and other instruments for the control of light reveals the fact that optical instruments are, in general, devices for bending or reflecting light rays. Lenses and prisms are the light benders, and mirrors and prisms are

The law of reflection of light is illustrated below. When a ray of light strikes a mirror at a certain angle, it is reflected from the mirror at the same angle. Light bounces off the mirror just as a billiard ball bounces off the cushion of a billiard table.

Courtesy General Motors Corporation



the light reflectors. Hence, an understanding of how light is controlled must be built upon a knowledge of the ways in which these simple things influence light waves which strike them.



Courtesy Bausch and Lomb Optical Company

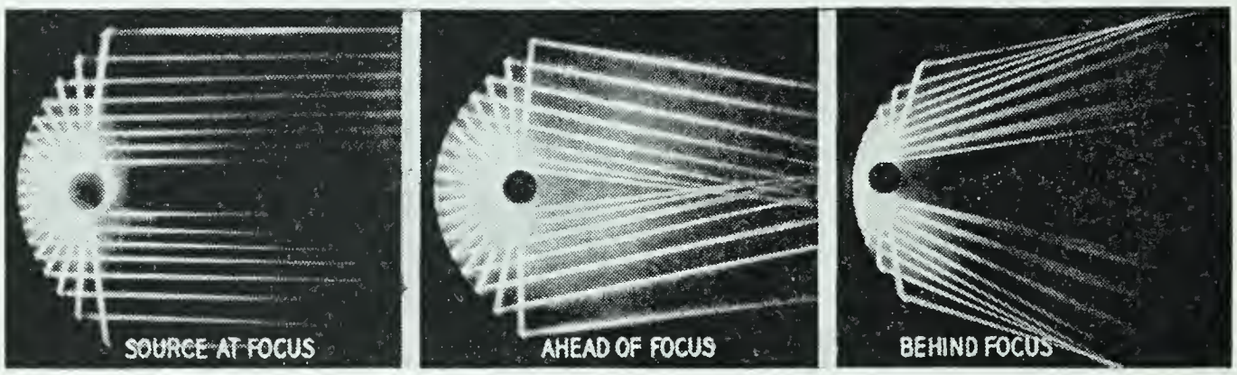
Benjamin Franklin, by his invention of the bifocal lens in 1784, gave the great gift of youthful vision to generations of spectacle wearers.

• REFLECTING AND BENDING LIGHT

Before the twelfth century looking glasses were unknown. The mirrors of the ancients were made of highly polished metal. Even today the reflecting surface of the familiar glass mirror is a thinly deposited film of metal, usually silver, but vaporized aluminum is coming into considerable use. In the use of mirrors to control light, man has duplicated something which he experienced in nature every time he bent over the calm surface of a spring or pool to satisfy his thirst. He must have noticed very early that he could distort the image and even make it disappear as he ruffled the water and completely destroyed its smooth surface. It was probably much later when someone noted that the images in such mirrors are reversed; that is, the right side of the object appears to be on the left side in the image. Look at the image of a printed page in an ordinary mirror and two facts become obvious: (1) the letters are reversed; (2) they remain erect or, in other words, with the top side up. Plane mirrors give the impression that the image is as far behind the mirror as the object is in front of it. This type of mirror properly placed above the windshield is standard equipment on automobiles because it gives the operator an essentially true picture of the road behind him.

Curved mirrors serve special purposes in light control. Delving into your own experience with them, you may recall laughing at distorted images of yourself in curved mirrors at some amusement center, or you may know of their widespread use in automobile headlights. The widely used curved mirrors are really parts of spheres, cylinders, paraboloids, or ellipsoids. When the surface

The skilled lighting engineer uses many important optical principles in designing scientific lighting. He knows that accurate control of light requires the use of shiny surfaces for reflectors. He understands how to design reflectors that will send light where he wants it to go, for light travels in straight lines unless otherwise directed. Home movies, as well as those at the theaters, depend upon precise principles of reflection. These unusual pictures, taken in the lighting laboratory, show how light is controlled by some of the objects we meet in our daily lives.

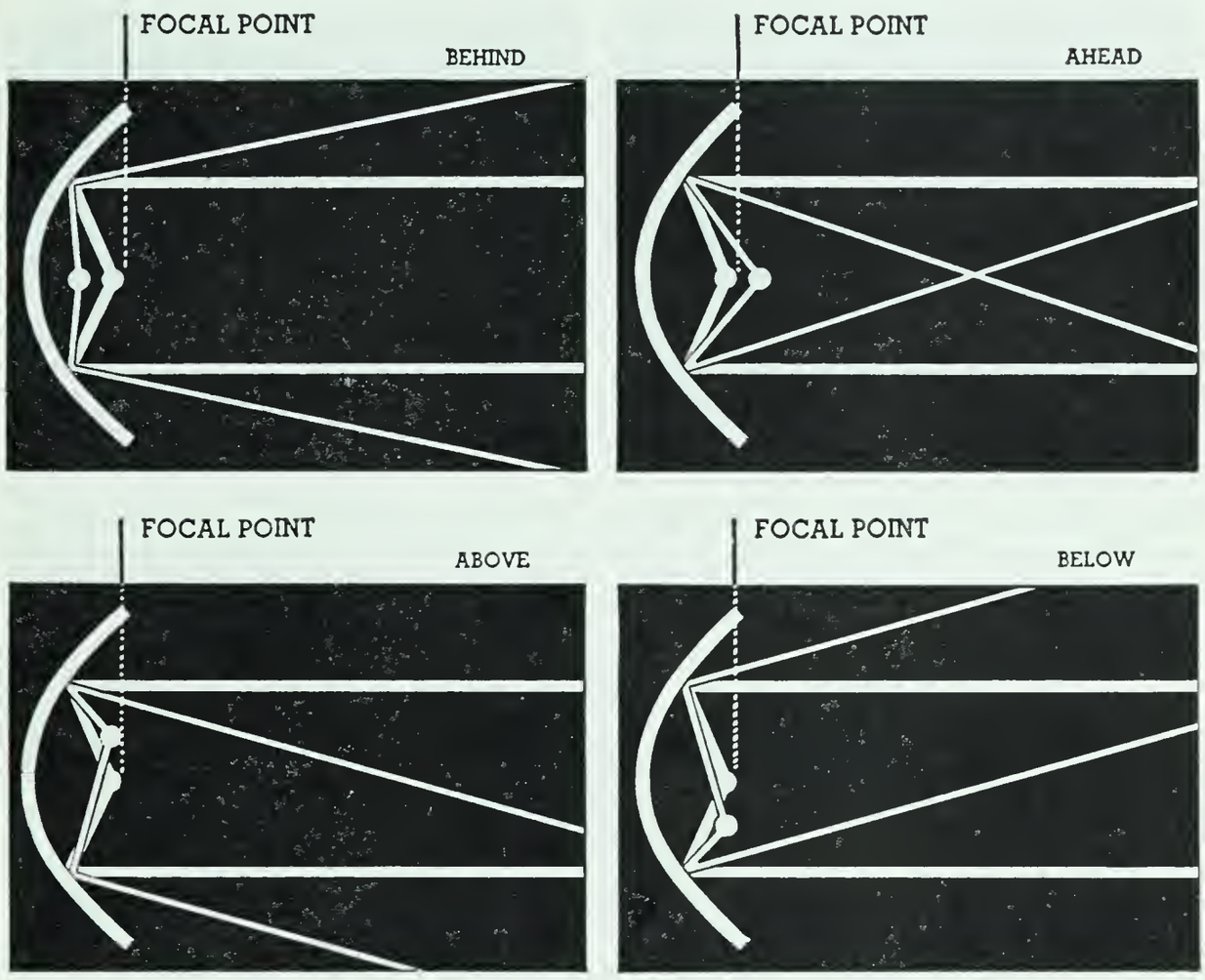


Parabolic reflector: The photo at the left shows how light is controlled in searchlights, spotlights on the stage, automobile headlights, etc. The mirror is a parabola, or section of a cone. Notice how it reflects light rays essentially parallel in the first photo. In the second and third photos, the light is off focus, and there is a loss of control.



Photos courtesy General Electric Company

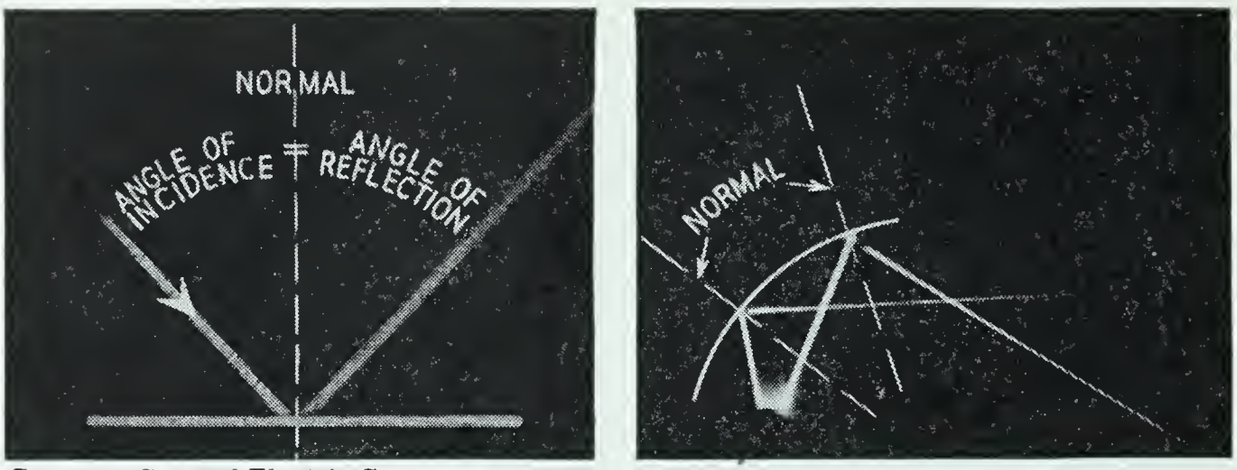
Spherical reflector: Movie projection machines, some large floodlights, as well as bulbs silvered on the round end to provide indirect lighting, make use of a spherical reflector like this one. When the light source (or filament in the case of the bulb) is at the center of this sphere, as in the first photo at the left, the rays are reflected evenly back through the source. In projection machines more light is thus redirected toward the condensing lens. But when the light source is off focus, as in the second and third photos, totally different light patterns result.



Courtesy General Motors Corporation

A parabolic reflector will reflect parallel beams of light only when the light source is at the focal point. Automobile-lamp bulbs are so accurately made that the filament is at the focal point when the bulb is put into the socket. If the light filament is above the focus, the major portion of the beam is tilted down. Deliberately offset filaments are used to control the beam and make it move up and down in the two-beam headlighting system.

which bulges outward is used as the reflector, the mirror is a *convex* mirror. When the opposite surface is used, the mirror is *concave.* Concave mirrors are used as reflectors in searchlights, spotlights, automobile headlights, and movie projection machines. They can be used to bring parallel rays of light to a point or focus. The focus is more exact if the concave mirror is shaped like a parabola than if it is spherical. When a source of light is placed at the focus, the reverse effect is obtained, and the reflected rays are parallel as shown in the diagram. Note in the pictures how reflection can be controlled by moving the light source in relation to the focus of parabolic and spherical mirrors. The parallel reflection when the light source is at the focus of a parabolic mirror shows how light is controlled in searchlights and headlights.



Courtesy General Electric Company

The photo at the left shows the law of reflection of light for a plane mirror. Explain how the photo at the right demonstrates the application of the same law to a curved mirror.

It is essential that the setup be accurate in all details in order to obtain the best possible results.

Curved mirrors may also be used to obtain images. Convex mirrors, like plane mirrors, produce only one kind of image. This image is similar to that of plane mirrors in being always erect, but it is different since it is always smaller than the object. This type of mirror placed on the fender or the cab exterior gives truck drivers a view of the road behind them.

With a concave mirror, the image obtained may be right side up or upside down; if inverted, the image may be the same size as the object, or it may be larger or smaller. Which kind of image is obtained depends upon how much distance intervenes between the mirror and the object. The inverted images of the concave mirror differ from the erect images, in that they are *real* and not *virtual.* Real images can actually be thrown upon a screen while virtual images cannot.

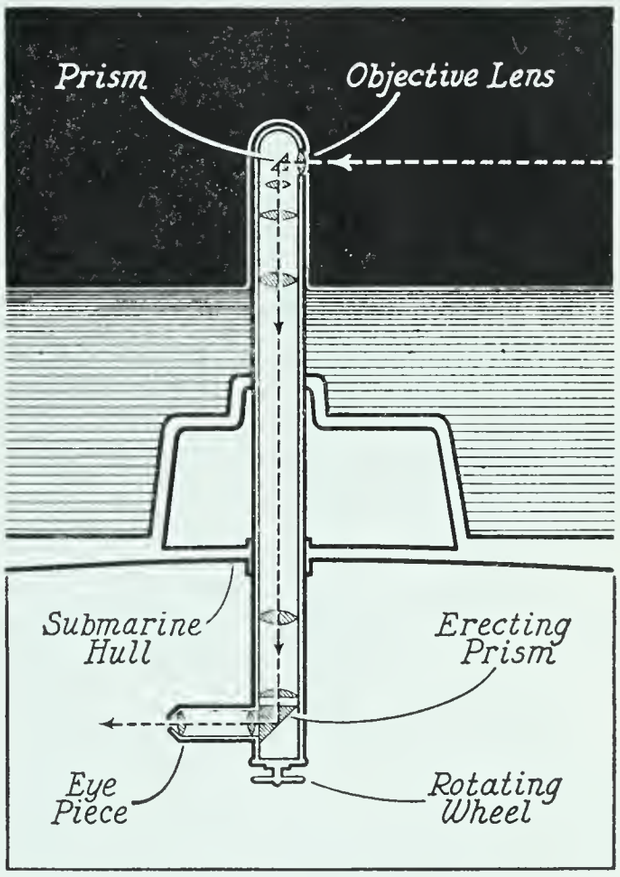
A right-angle prism is an even more efficient reflector than a mirror and is used instead of mirrors in such optical instruments as the periscope, binoculars, and range finders. The arrangement of prisms as reflectors in a periscope is shown in the diagram.

Lenses and prisms are the light benders. We have already explained how the difference in the speed of light in two different transparent materials is responsible for the bending which occurs when a light ray passes from one into the other. When a lens or prism does the refracting, the amount of this bending depends upon the shape of the lens or prism and the material of which the lens or prism is made. In general, there are two types of lenses: (1) convex lenses, or those which are thicker at the middle than

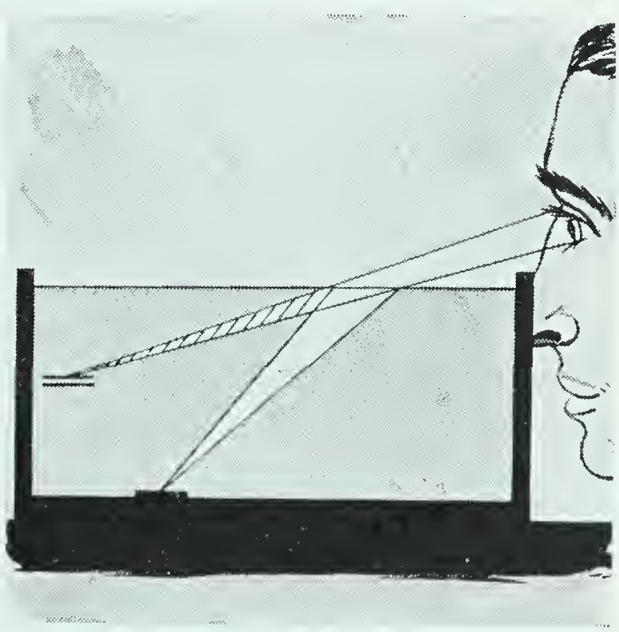
at the edges; (2) concave lenses, which are thinner at the middle than at the edges. The former cause parallel light rays to converge and bring them to a focus. Convex or condensor lenses take light from a point and form it into a beam of parallel rays. Concave lenses cause the rays to diverge so that they get farther apart. How lenses and prisms function is shown in the diagrams at the right and in the illustrations on the next page. Study the legends carefully.

• CONTROLLING LIGHT FOR BETTER SIGHT

The eye ranks first among optical instruments because all the others are its helpers. Although it is more intricate than any other in its functioning, the eye possesses relatively few and simple parts. One of its parts is a convex lens which is rated next in importance in the seeing process to the light-sensitive nerves themselves. It is an extraordinary lens which changes in thickness or curvature under various conditions. The thickening of the lens increases its ability to focus light rays; when the lens becomes thinner, this ability decreases. Since the parallel rays of light coming from distant objects are easier to focus than the more divergent rays from close

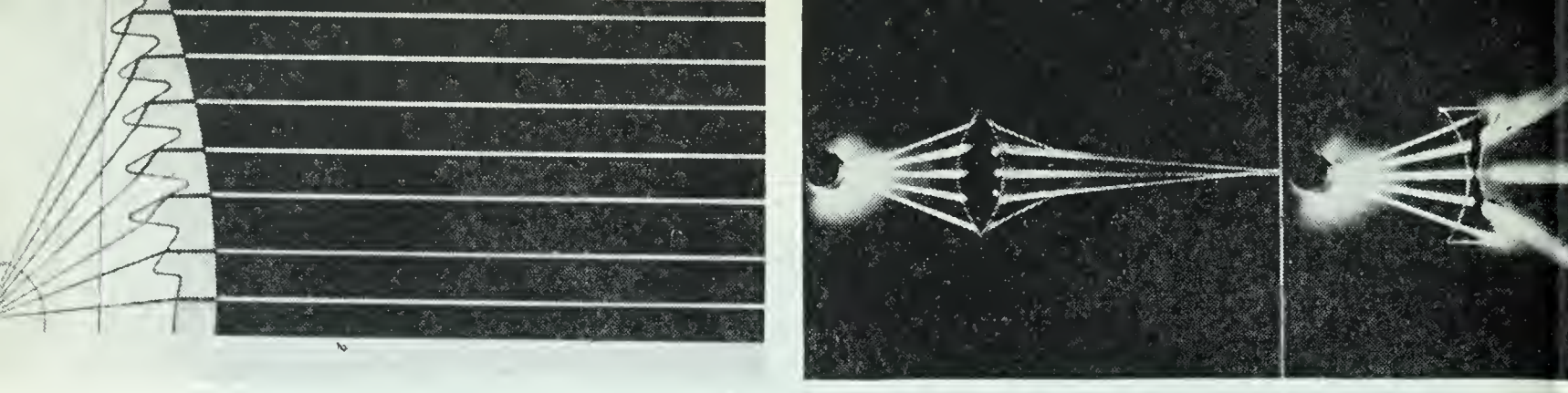


Right-angle prisms serve as reflectors of light in the submarine periscope.



Courtesy General Motors Corporation

What is the meaning of this drawing? How does it explain why when we look into clear water, it appears much shallower than it really is—a good fact to remember when swimming in strange lakes?



Photos courtesy General Motors Corporation; General Electric Company

Left: Light beams from an automobile tail-light are parallel and horizontal. The outside shape of the glass may be complicated to conform to the style of the rear end of the car, but the illuminating engineer has designed prisms for the glass which control the light and make it behave. How do tail-lights on a car help us to judge its distance from us?

Right: Railroad signals, traffic signals, auto headlights, etc., use lenses. A lens may be considered as a system of prisms. The fluting on the front of a headlight is really a combination of prisms, each placed in relation to the others so as to produce whatever beamed pattern is desired. The same principles of light control are involved in the design of eyeglasses. The two photos show convergence with a double convex lens and divergence with a double concave lens. Can you show that each of these lenses is really composed of two prisms?

objects, some such adjustment by the eye is necessary or not all images would be produced upon the retina. When the lenses do fail to produce the images exactly upon the retina, nearsightedness or farsightedness results. In the former, only near-by objects are seen clearly, and the reverse is true in farsightedness. Eyeglasses are the only means for correcting these defects.

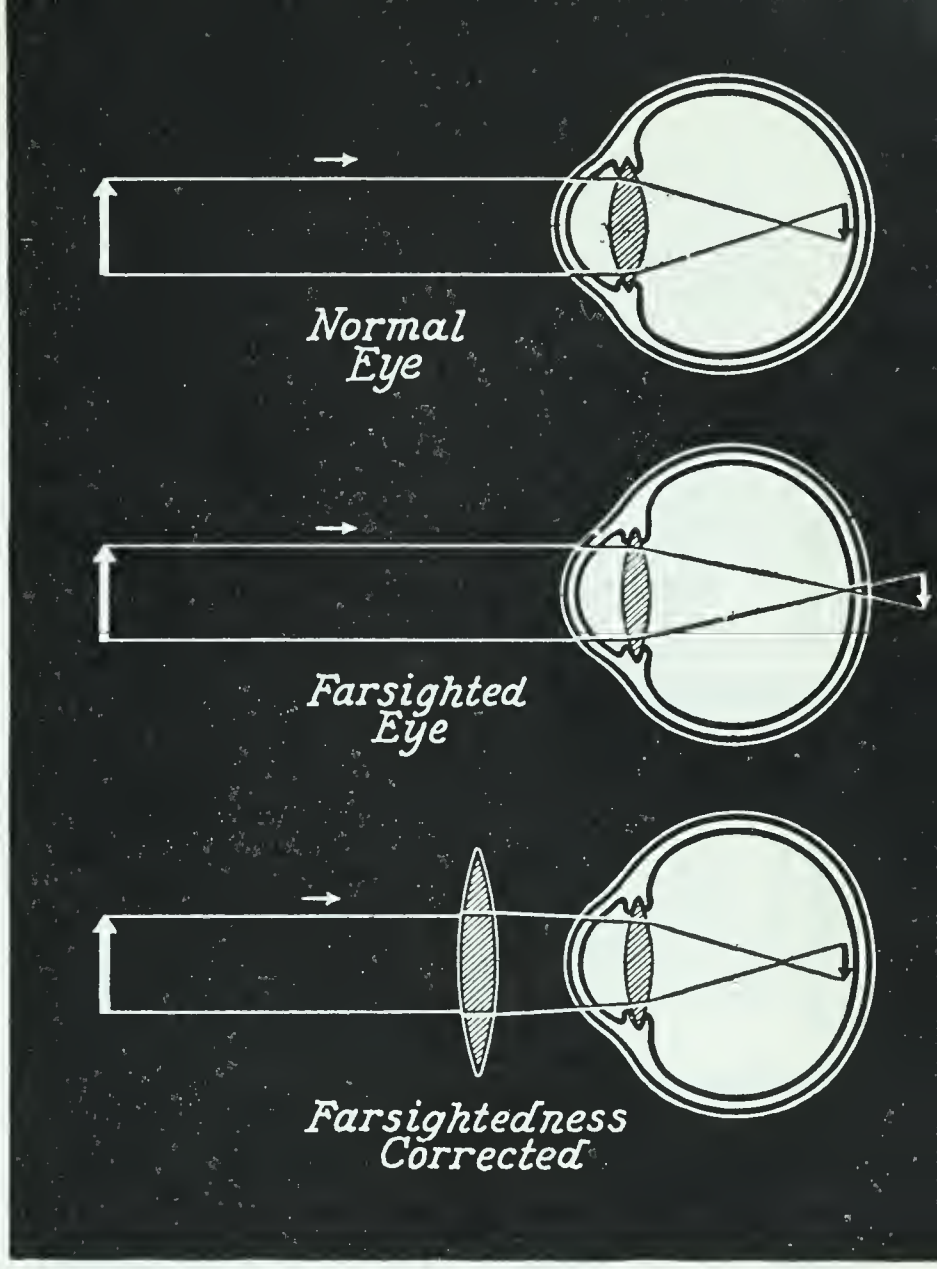
A concave lens of the required power placed in front of a nearsighted eye diverges the rays somewhat so that they strike the eye at the angle necessary for correct vision. Then the image falls upon the retina as desired instead of in front of it. A convex lens is used in farsightedness to add to the eye's focusing power because there is not sufficient distance between the lens and the retina for proper image formation. The eyes of middle-aged persons frequently need help for both far and near vision. Bifocal lenses are then prescribed.

Unequal curvature of the cornea or the lens produces blurring in the vision. Properly ground, cylindrical lenses restore clear vision to those having *astigmatism,* as this defect is called. The other common eye defect, which results in double vision, is commonly called crossed eyes. It is largely caused by the failure of the muscles of the two eyes to work together properly. Eyeglasses are very essential to those suffering from this defect, because they not only improve the vision and relieve strain but may help strengthen weak muscles. If the glasses are obtained early enough

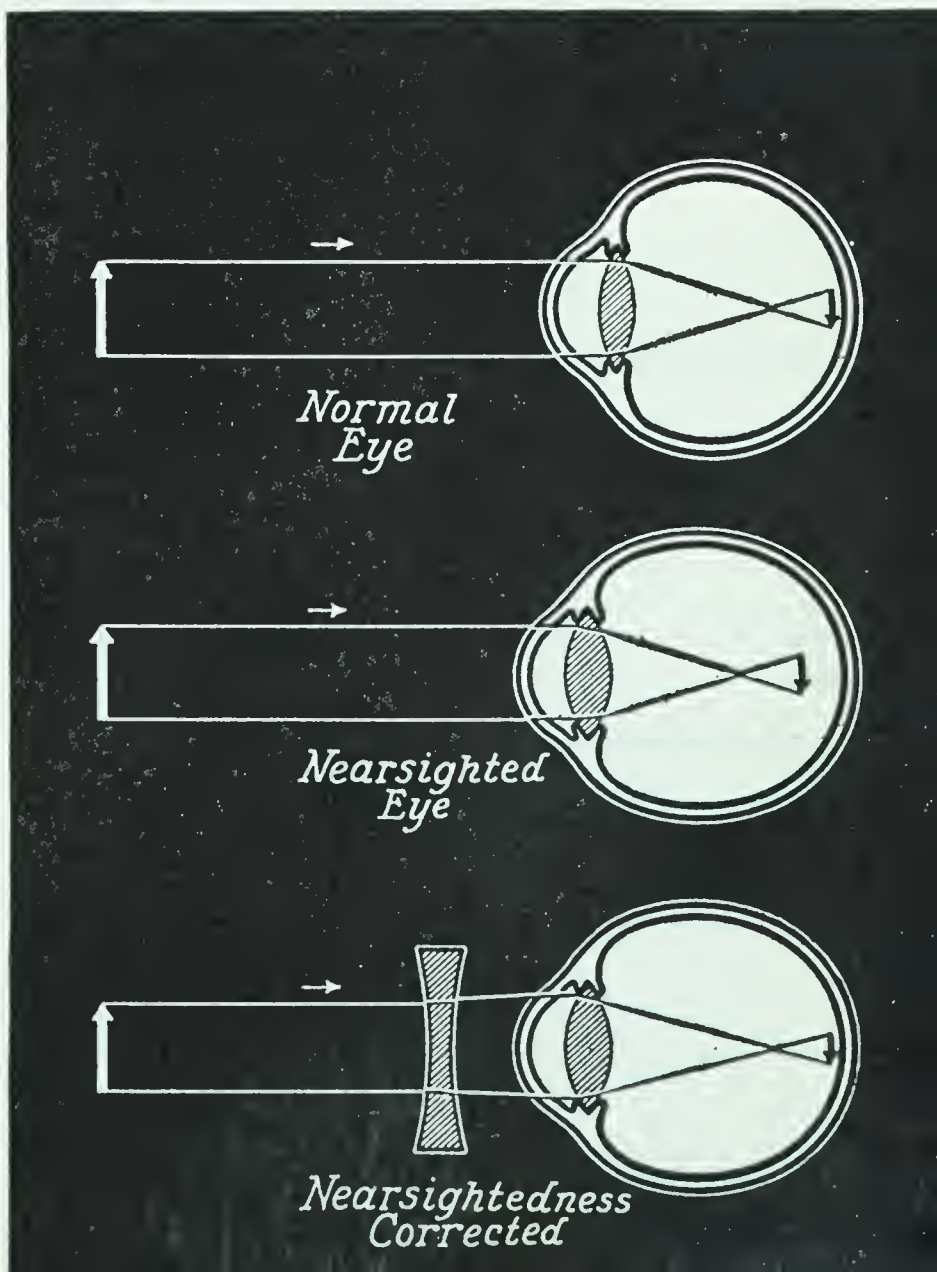
and changed as the eyes improve, the defect can often be entirely overcome.

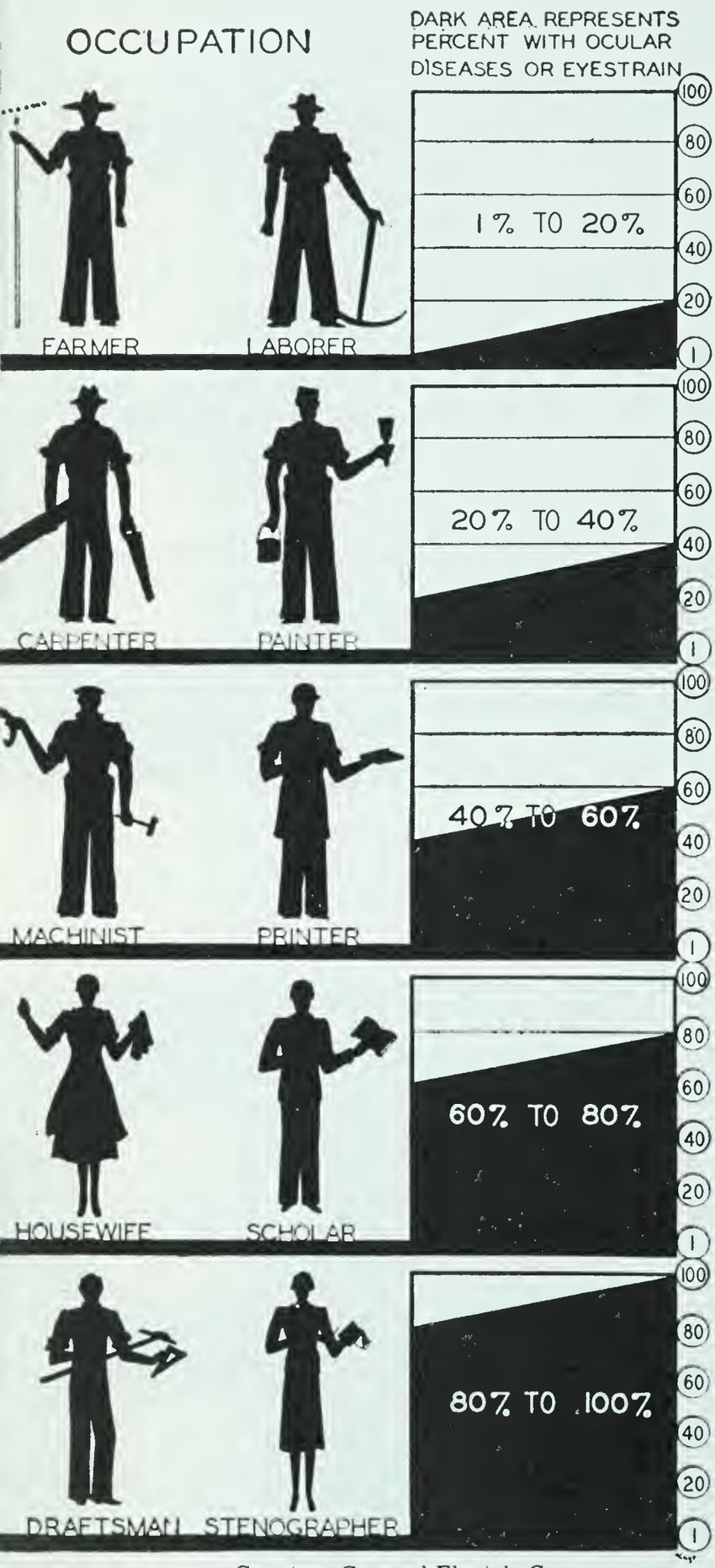
To have perfect eyes is the exception and not the general rule. The Better Vision Institute reports that seven out of every ten persons need glasses, although only two have them. Many of those who should wear glasses do not realize that they need them. As a result, they miss the pleasure of having their best possible vision and wastefully work with impaired efficiency. This explains why many business concerns insist upon an eye examination for every employee. *Periodic eye examinations at least once a year, whether or not you feel the need for them, will be a good investment for you!*

Leeuwenhoek and Galileo led the way to the discovery of new worlds without having to leave their own workshops—they did it with convex lenses. Leeuwenhoek enlarged the known universe by revealing the existence of millions of plants and animals too small to be seen with the unaided eye. He did more than this, because the microscope really laid the basis for a revolution in thought about many everyday occurrences. Without it, Louis Pasteur, the father of bacteriology, never could have exploded the myth of spontaneous generation by showing



Eyeglasses are the only means of correcting faulty vision and eyestrain resulting from nearsighted and farsighted eyes.





Courtesy General Electric Company

Occupations and poor seeing conditions leave their mark on eyesight.

that microscopic yeast plants, molds, and bacteria are the real causes of fermentation and decay. Because decaying matter abounds with all sorts of life, scientists had previously come to the quite natural conclusion that animals were the product of decay. Indeed, Jan van Helmont, a Belgian physician who died twelve years after Leeuwenhoek was born, had gone so far as to assert that mice could be produced by mixing meal with dirty rags. It seems ridiculous to us that an outstanding scientist of a few centuries ago should be offering this sort of explanation, but we must remember that he had no way of getting at the correct answer. Some of the hypotheses scientists offer today in attempts to explain the mysteries about light will no doubt bring smiles to the countenances of later generations. There is, however, a real difference between the Middle Ages and the present in the attitude toward the teachings of great men. We are taught to distinguish between what has been proved and what has not been proved. A hypothesis put forth by even the most distinguished scientists is, as he is the first to admit, only a guess—an opinion based upon careful observation and experimentation. A war of words, a decree of the civil or

religious authorities, or a majority vote cannot decide its truth or falsity. Only adequate testing can do this, and the decision must wait until someone discovers how to do the testing.

The telescope has, in a sense, made the universe grow smaller. It enables us to observe distant objects as though they were near at hand. With the telescope astronomers can study stars which are so far away that light coming from them at the rate of 186,000 miles a second takes millions of years to reach the earth.

The diagram on page 512 illustrates a simple refracting telescope and a microscope made from pairs of convex lenses. Notice that the object is always far away from the objective lens of the telescope, but always very close to the objective lens of the microscope. In the telescope, the rays which pass through the objective lens form a small real image, which serves as the object to be magnified by the eyepiece lens. The eyepiece lens then forms a larger virtual image of the object.

Whereas the objective lens of the refracting telescope has much greater focal length than the eyepiece, both lenses of the microscope have short focal lengths which may or may not be equal. The small objective



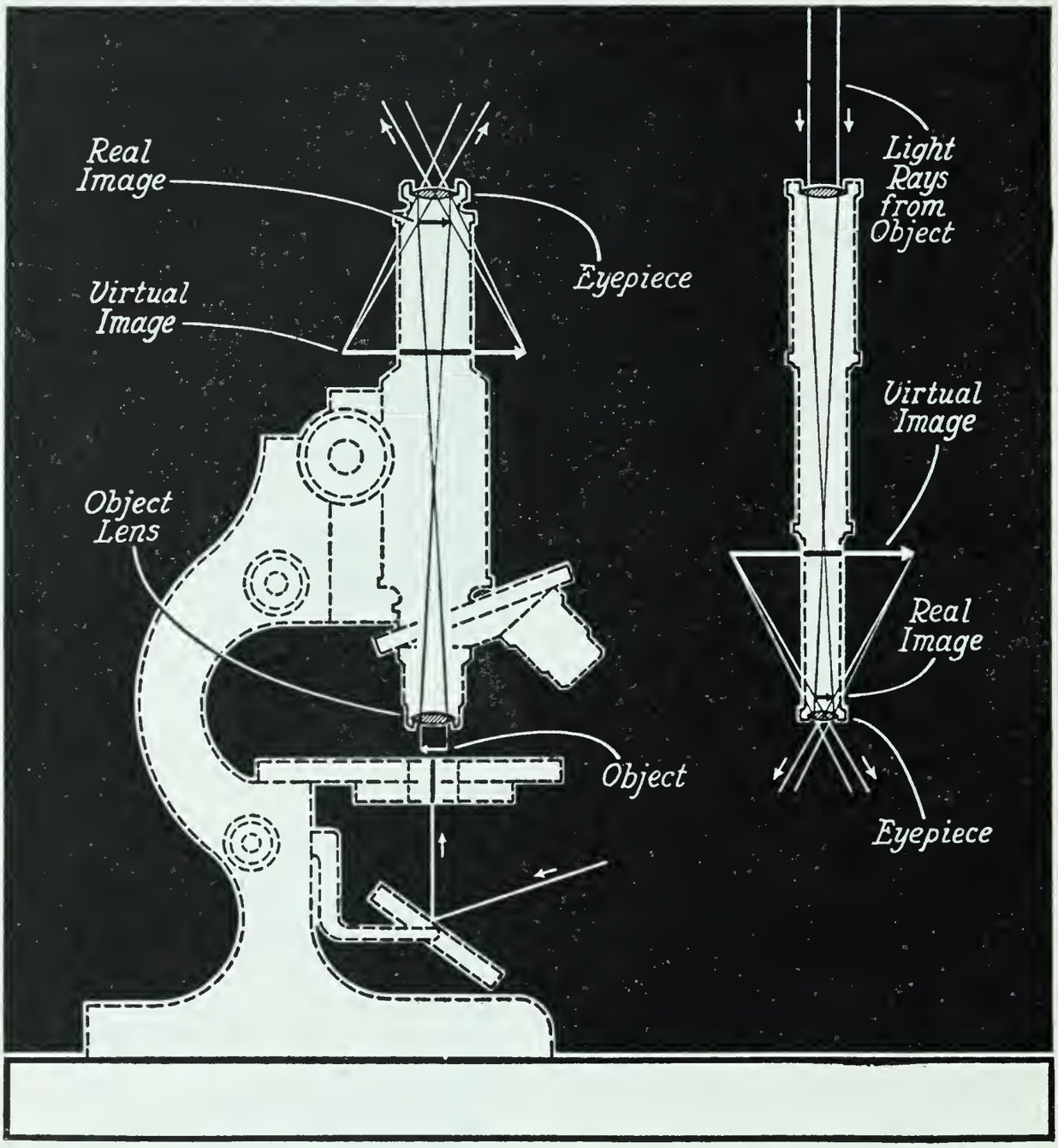
Courtesy Bausch and Lomb Optical Company

Top: A most significant event was the discovery of bacteria in 1675 by Anton Van Leeuwenhoek, who used a primitive microscope of his own manufacture.

Bottom: In 1609 Galileo was acclaimed by distinguished citizens of Venice when he demonstrated his first telescope from the Tower of St. Mark's.

Courtesy Bausch and Lomb Optical Company





Two convex lenses correctly chosen and properly placed with respect to each other and the object give us the microscope and the telescope.

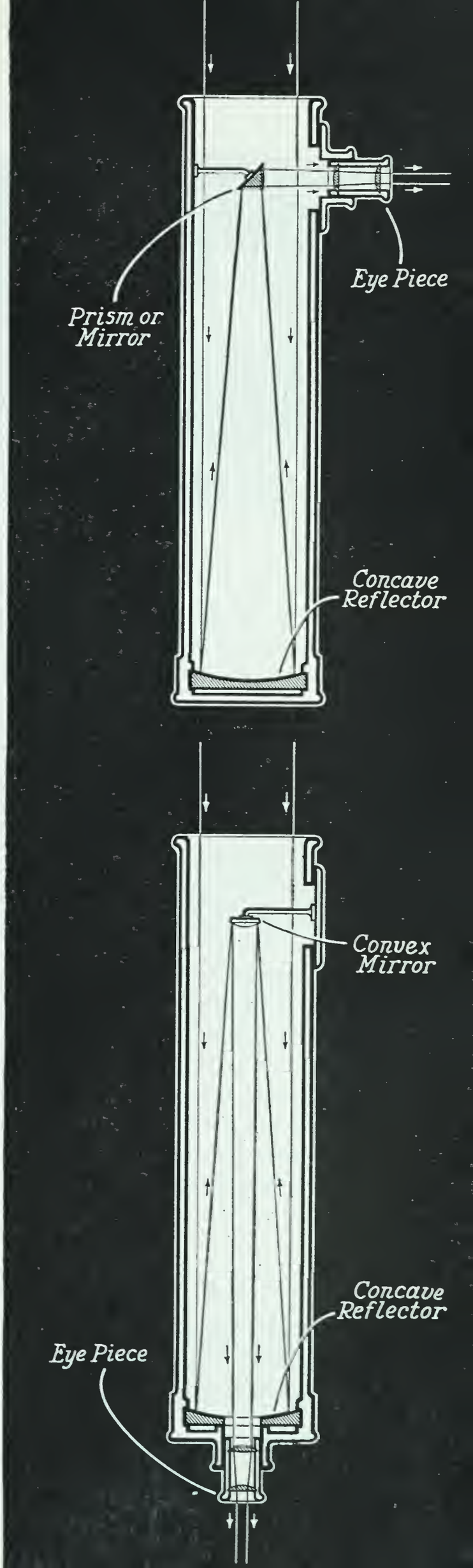
lens of the microscope forms an enlarged real image, which is used by the eyepiece lens, as in the telescope, to form a still larger image of the object studied. Thus both lenses of the microscope magnify, whereas the objective lens of the telescope produces a reduced image which the other lens magnifies.

The image in both of these instruments is inverted. In telescopes used for viewing objects on the earth, a surveyor's transit, for example, inverted images would be a disadvantage. Therefore, terrestrial telescopes have another convex lens placed between the objective and eyepiece lenses to invert the image once more so that objects will not be seen upside down.

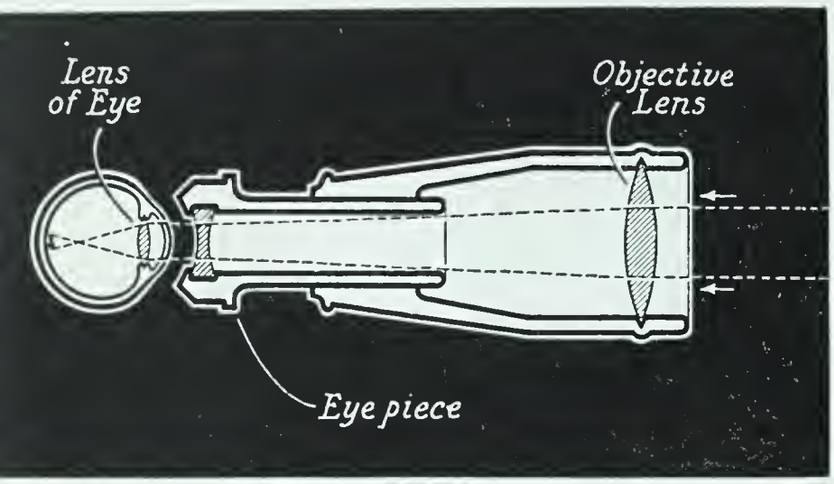
The largest astronomical telescopes have a concave mirror

instead of an objective lens for collecting the light rays. The mirror forms a real image which is magnified, as in the refracting telescope, by a convex eyepiece lens. The reflecting telescope has a number of advantages over the refracting type. Among these is the fact that large mirrors are less difficult to make than large lenses. A diameter of 40 inches is indicated by practice as about the practical limit of refracting lenses, but the makers of the new 200-inch reflector for the Mount Palomar observatory are convinced that they could make still larger ones. The larger mirrors of reflecting telescopes have greater light-gathering capacity and hence bring into view millions of stars that cannot be observed in any other way. Since the mirror is placed at the bottom of the observing tube, it is less subject to drafts than is the objective lens of refracting telescopes. Changes in temperature caused by drafts cause unequal expansion and contraction, which changes the shape of the glass and consequently distorts the image formed by it.

Opera glasses and bird glasses have a magnifying tube for each eye. They often consist of a concave eyepiece lens which is designed to neutralize the bending action of the lens of the eye. In this way, a magnifying objective lens is, in effect, substituted for



These are the two common types of reflecting telescopes.



The lens arrangement of opera glasses and bird glasses is shown in this diagram.

the lens of the eye. Opera glasses usually magnify only three or four times. The inverted image formed on the retina enables us to see the object in its natural position. This is not a contradiction, as it may seem, when we realize that all images formed on the retina in the normal manner by the eye lenses are inverted. Just how the central nervous system reinverts them is an unsolved mystery.

Another more efficient type of binocular is really two telescopes mounted to serve both eyes. The length required in a telescope, principally because of the long focal length of the objective lens, is greatly reduced by the clever use of reflecting prisms as shown in the illustration on the next page.

When selecting binoculars or opera glasses, two items besides magnifying power should be considered—the quality and the size of the lenses.

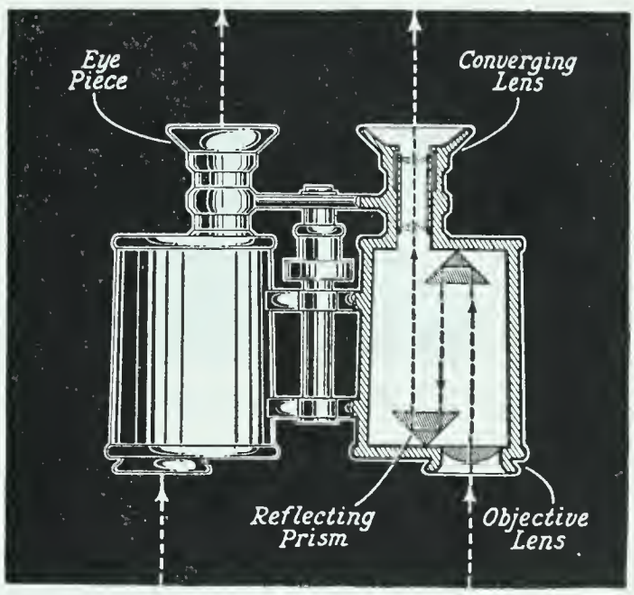
The clearness of vision depends primarily upon the quality of the lenses. To prevent the production of color by refraction, high-grade optical instruments employ *achromatic* lenses. An achromatic lens usually consists of one section of flint glass fitted into another of crown glass.

It must also be remembered that the size of the lenses determines the amount of light admitted. This becomes important when observations are to be made on dark days or in poorly lighted interiors. For observing rapidly moving objects, binoculars which magnify things five or six times are likely to prove more satisfac tory than those whose power of magnification is considerably greater. This is due to the difficulty experienced with the latter in trying to follow the moving object.

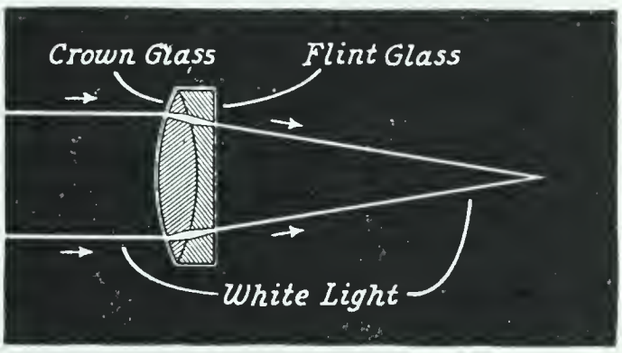
• RECORDING AND REPRODUCING LIGHT

In a projection lantern, a convex lens forms a real image upon a screen. This projecting lens is mounted near one end of a light-proof box, and behind it, in order, are the slide holder, the con-

denser lenses, and a powerful light source. There may also be a concave mirror behind the light source to redirect stray light through the filament and into the optical system. The job of the convex condenser lenses is to refract the scattering light rays of the light source and direct them in a slightly converging beam toward the lantern slide. Moving the objective lens backward or forward brings the image into sharp focus upon the screen.



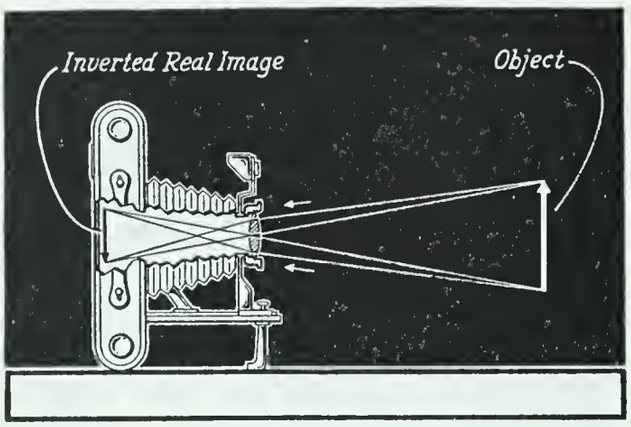
The prisms in this type of binocular reflect the light so that it travels up and down the tube three times. This produces as much magnification as though a tube nearly three times as long, but without prisms, were used.



Achromatic lenses, made by combining two or more kinds of glass with different optical properties, focus white light without breaking it up into the spectral colors.

The motion-picture projector has the same parts as the projection lantern for "stills" plus two important additions: (1) a motor for moving the film; (2) a shutter for cutting off the light while the film is being moved forward in jerks from one picture to the next. When the pictures are flashed on the screen in rapid succession (usually 16 pictures a second for silent films and 24 a second for "talkies"), the eye sees a continuous picture. It retains each individual picture a short time after the picture is really gone from the screen and blends this heldover image with the next one thrown upon the screen. Because of persistence of vision, we do not realize that the screen is dark nearly half the time. Here "after-images" are of value—in industry, on the highway, etc., they are dangerous.

The film is a series of pictures of a moving object taken in rapid succession at about the same rate as they are projected. Each individual picture differs at most only slightly from the one before it. The lag and blending in our vision when these pictures are properly flashed before our eyes has made possible one of our country's



With the aid of this diagram can you explain why the camera lens is moved nearer the film when photographing distant objects and farther from the film when photographing near-by objects?

largest industries.

Photography is one of the most popular of all hobbies. A camera can be purchased for very little or for hundreds of dollars. It is even possible to make a pinhole camera which will take pictures, but a camera with a lens is more efficient since it is then possible to concentrate and control the light. The cost of a camera depends to a large extent upon the quality of its lens equipment and accessories.

The camera and the eye are remarkably similar in their parts and operation. Perhaps the most outstanding difference is that the shape of the lens of the camera remains fixed, while that of the eye has the unique ability to undergo change in shape. Consequently, the camera must have some other arrangement for bringing into focus objects at various distances from it, or, like the ordinary box camera, it will focus sharply at one distance only. The use of bellows for changing the distance between the lens and the film is a very common means of adjusting the focus before taking each picture. This makes it possible to take a clear picture of an object from any of a large number of distances away from the object, instead of having to be at a fixed distance from it.

As in the eye, the lens or lens system of a camera is of the converging variety. An achromatic lens is, of course, preferable to one which disperses the light into colors. Lenses tend to produce distortion in pictures, more of the distortion being caused in the part of the picture focused by the margin of the lens than in the areas focused by the middle of the lens. "Rapid rectilinear" is a name given to one type of lens which is specially ground so as to eliminate some of this distortion. Lenses called "anastigmats" are still more highly corrected and form more exact images. With these lenses, it is possible to make satisfactory use of more of the lens area than is practical with uncorrected lenses. Corrected lenses, particularly the anastigmats, give a camera greater versatility in the sense that they make it possible to take good pictures under poor lighting conditions and also enable one to photo-

graph fast-moving objects without having the object blurred in the picture.

The depth of focus—that is, the range of distance within which a lens will focus objects well—increases as the camera opening is made smaller by the diaphragm, or stop. Pinhole cameras are "best" in that chromatic and astigmatic errors are almost nil. Slow diaphragm or "f" stops approach this and gain depth of focus which is nearly 100 per cent in pinhole type cameras. However, when less light enters the camera, the brightness of the image diminishes. Sometimes this can be compensated for by using artificial illumination, such as that furnished by photo-flood and photo-flash lamps. This is not always practical. Moreover, the length of time necessary for proper exposure is another factor to be considered. The proper exposure of a film requires a definite amount of light energy, and the obtaining of this energy depends upon three things: (1) the brightness of the objects to be photographed; (2) the size of the camera opening, or stop; (3) the length of the exposure time.

The interplay of the above three factors is well illustrated in the taking of "action shots." To prevent blurring, the exposure time must be very short. This in turn necessitates a relatively large diaphragm opening to admit more light. Even with the best available illumination, a wide-open stop, and a very sensitive film, a camera without a "fast" lens cannot get enough light energy to take clear, unblurred pictures of rapidly moving objects. Fast lenses are those which are corrected to prevent distortion when the margin of the lens, as well as its center, is used to focus light upon the film. Cameras with fast lenses also need fast-closing shutters in order to get short exposure time. Shutter speeds of 1/300, 1/400, or even 1/1000 of a second are quite common.

The "f" system is used to indicate the speed of the lens. One can generalize from the definition of "f" ratings that the smaller the "f" rating, the faster the lens. Technically, the "f" rating is obtained by dividing the focal length of the lens by the diameter of that part of it which is practical to use. Thus, a lens which has a focal length of 3 inches and a usable opening, or aperture, of ½ inch is given an f.6 rating $\left(\frac{3''}{\frac{1}{2}''} = 6\right)$. An f.3 lens is four times as fast as an f.6 lens and sixteen times as fast an an f.12 lens. A lens can be used at smaller openings than the maximum indicated by its "f" value. Even in corrected lenses, smaller stops give sharper

detail in the picture, but they, of course, require longer exposure time.

Range finders, to indicate when the camera is properly focused, and exposure meters, to help one decide what lens opening and shutter speed to use for each picture, eliminate much of the guesswork in photography. However, like high-speed lenses, they add to the initial cost—but they save a good deal of waste and insure greater satisfaction.

Those wishing to take up photography at comparatively small cost need not be discouraged, since excellent pictures can be taken with an inexpensive "fixed-focus" camera. While the lack of speed and versatility place certain limits on its usefulness, the fact remains that amateur photographers can take excellent pictures with such a camera. Manufacturers have greatly increased the sensitivity of films during recent years, and this has shortened the length of time needed for proper exposure. Consequently, it is possible to take pictures with a cheap camera which formerly could have been taken only with a more expensive one. Moreover, it now costs comparatively little to provide photo-flood and photo-flash illumination and use the inexpensive camera for indoor as well as outdoor photography.

Modern photography owes its existence to the fact that light and similar radiations provide energy which causes chemical action in certain silver compounds. A compound in which silver is chemically combined with the element chlorine, bromine, or iodine is blackened when exposed to light because the action which results frees some of the silver. The darkening is due to the fact that finely divided silver is black. Silver bromide and silver iodide are very sensitive to light, and the silver bromide, in particular, is used in large quantities for making films. Various mixtures of the silver compounds in finely divided form are suspended in gelatin and then spread on glass plates or plastic films made from cellulose nitrate or cellulose acetate. When dry, the sensitive coating is ready for exposure in the camera.

The special properties of each film depend largely upon the particular mixture of chemicals used in making the sensitive coating. For example, some films are faster in their action than others and therefore require shorter exposure time. Films also differ in the degree to which they are affected by the different wave lengths which strike them during exposure. Ultraviolet light affects all of the common films used in ordinary photography, but infrared rays do not. Hence films to be used for taking pictures in infrared

says must be specially made, and the camera in which they are exposed must be equipped with a filter to prevent the entrance of ultraviolet radiation.

When a film is exposed, the amount of darkening produced is proportional to the quantity of effective radiant energy which strikes it. This radiant energy in ordinary photography is, of course, mostly visible light. At best, the chemical action is only partial and the result of the action of the light is not visible until the film is developed. The developer first acts upon the parts of the film which have been affected by sunlight. The film cannot be kept in the developer too long, or all of the sensitive coating is changed into finely divided silver. This explains why the film is kept in the developer just long enough to produce an image of desired intensity and to avoid overdevelopment. The development must be done in a room in which there is only faint red light or, for some kinds of film, no light whatsoever. The unaffected silver salt is removed by dipping the film into a solution of sodium thiosulfate, or hypo. This is called fixing. The changed film is called the *negative,* because light-colored objects appear dark on it and vice versa.

The finished picture is made by placing the negative over a piece of paper which is like the original film in that it has a sensitive coating of silver salts suspended in gelatin. This is then exposed to light for a suitable length of time. During the exposure, the dark areas of the negative hinder the passage of light so that the sensitive silver salts beneath these portions get little or no light energy. The exposed paper is then put through the developing and fixing baths in much the same manner as was the exposed film. In this way the light and dark areas on the negative are reversed on the *positive,* as the finished picture is called. The positive corresponds to the scene that was photographed.

Special treatment during the processing of the negative or positive can be used to produce desired effects. It is possible to remedy overexposure and underexposure or poor development, to produce brown or sepia finishes, and to produce other tones of color. Films which produce pictures in natural color instead of the usual black and white are a comparatively recent development.

Exercises for Problem Study and Review

1. How are mirrors made?
2. Describe the type of image formed by a plane mirror.

3. List several uses for concave mirrors and indicate what property determines each use.

4. Describe the type of image formed by convex mirrors. List several uses for this type of mirror.

5. When is an image real? Virtual?

6. What reflects light better than mirrors? Show by a diagram how this is accomplished.

7. What is the essential difference between a convex and a concave lens? A lens and a prism?

8. In what respects are lenses of the eye similar to those of cameras? How do they differ from camera lenses?

9. What causes nearsightedness? Farsightedness? Astigmatism? How do they affect vision? How can each be corrected?

10. What causes eyes to be crossed? Why is it particularly important to begin treatment with glasses at an early age?

11. Do you see as well as it is possible for you to see? How would you find out?

12. How many people in the United States have defective vision? List some changes you would expect if 95 per cent of the defects were corrected, as is possible.

13. Compare the microscope, refracting telescope, and reflecting telescope as to: essential parts; how they work.

14. How did the invention of the microscope and the telescope influence our thinking about the world?

15. What are achromatic lenses? Why are they desirable in optical instruments?

16. What characteristics would you like to have in binoculars that you were going to use for the study of wild birds?

17. How does a motion-picture projector work? What characteristic of our eyes makes motion pictures possible?

18. What is a "fixed-focus" camera? What common device makes it possible to adjust the focus in other cameras?

19. Discuss the kinds of lenses used in cameras. What advantages do anastigmats contribute to a camera?

20. When preparing to take a picture what factors should be considered?

21. How are lenses made "fast"?

22. Which is generally more desirable, an f.3 lens or an f.8? Why?

23. How are films made? What change is produced in them when they are exposed?

24. What does the developer do? The fixing agent?

25. How is the positive made from the negative?

26. Discuss some recent developments in photography.

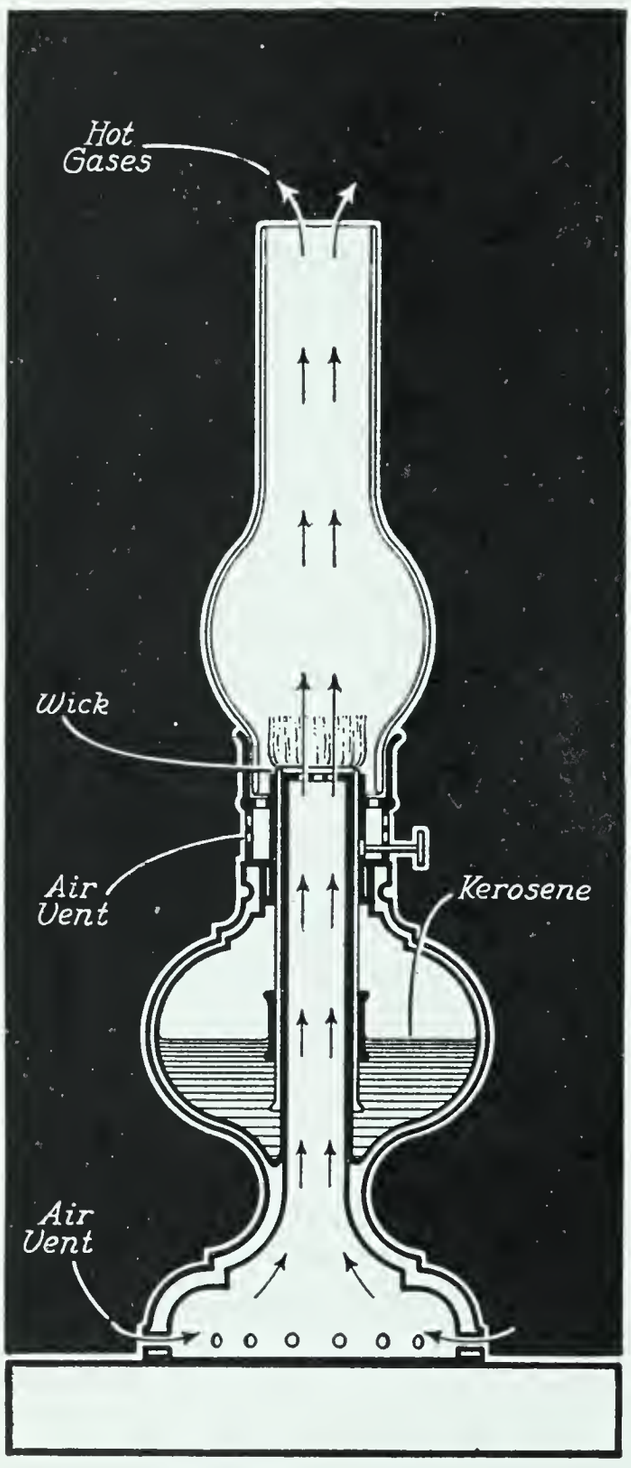
Problem 3: How can we provide proper illumination?

Much of the revolution in methods of overcoming darkness with artificial light has occurred since the birth of our country and a great deal of it within the life span of our grandparents. The visitor to George Washington's home at Mount Vernon is impressed by the variety of candle holders and their equipment with hurricane chimneys to reduce the flickering of the flames. The candles of 1800 were a great improvement over their predecessors—pine splinters and the greasy lamps fueled with animal fat, which to the early settlers were welcome additions to the illumination of the fireplace. Comparatively recent lighting devices include the kerosene lamp (1870), the gas flame (1880), and the mantle lamp (1901). Davy's first electric arc in 1801 and Edison's first successful incandescent lamp in 1879 paved the way for modern types of electric lighting and the displacement of flames as the dominant source of artificial light.

It is estimated that flames are still the source of illumination for one-quarter of American families. To a large extent, this occurs in rural districts where electricity is not available. Fortunately, there are on the market lamps equipped with mantles and other improvements for getting more and whiter light from liquid and gaseous fuels. However, an excursion into the country reveals the extensive use still being made of the old-type kerosene lamp with its very unsatisfactory yellow illumination. Even where electricity is used as a relatively cheap source of light, good illumination does not follow automatically. Proper lighting requires careful planning.

• HOW MUCH LIGHT?

The amount of light needed for good seeing depends upon the nature of the work being done. Our eyes tire rapidly when we use them in doing tasks for which there is not enough light. Even when the details of an object are visible, the light may still be inadequate because the eye muscles are overworked in maintaining the proper focus and convergence. In proper lighting the strain upon these muscles is less. We must remember that fatigue resulting in one part of the body does not remain localized. Tests show that prolonged use of the eyes in insufficient light causes nervous strain and tension in the whole body. As you would expect, the efficiency of the worker decreases.

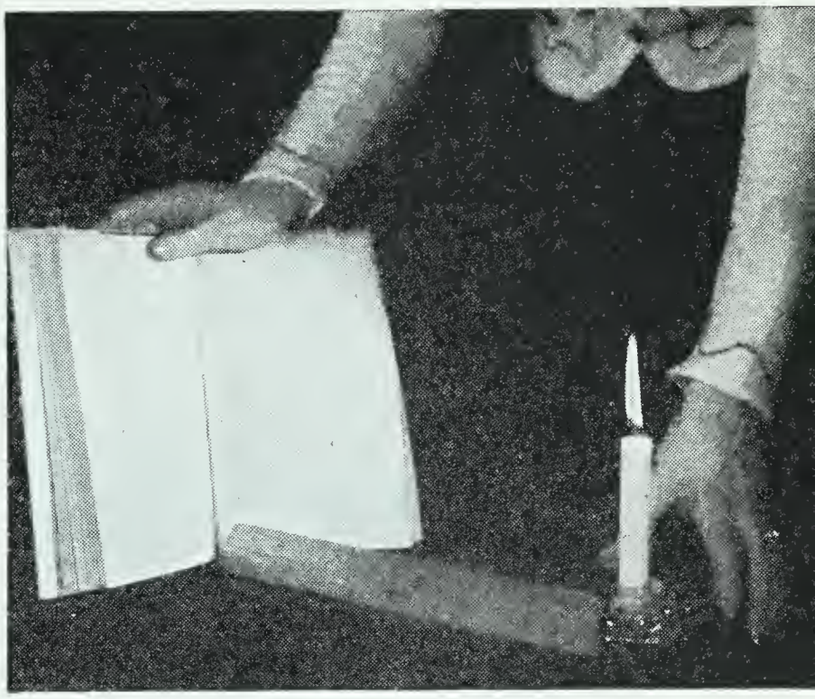


How is the flame of the kerosene lamp provided with the correct amount of fuel and air to give it the desired characteristics? Does this lamp represent an application of the Bunsen principle?

Obviously, some unit is necessary for measuring light *intensity*. The customary unit, the foot-candle, dates back to the candle age and is defined as the intensity of light delivered by a standard candle to a perpendicular screen one foot away. Outdoor illumination on a clear day may reach 8,000 to 10,000 foot-candles in the sun and 500 to 1,000 foot-candles in the shade. Very few interiors are artificially lighted with an intensity of 100 foot-candles. The average is something less than 10—1% of that under a tree on a bright day! In view of this comparison, it is easy to believe the scientist when he tells us that we can hardly get too much light—providing it is properly diffused and controlled. By comparison with the comfortable daylight of the shaded outdoors, illumination of 100 foot-candles seems rather small. However, if properly diffused illumination of this intensity were provided for all close work we would indeed be fortunate. Primarily because of cost, our eyes usually have to get along with less, but there are certain minimum requirements which should be met.

For school lighting, the American Standards Association approves 15 foot-candles as a minimum for general illumination on desks, tables, and blackboards; it recommends 25 foot-candles for shop and laboratory work and a minimum of 30 foot-candles on desks and blackboards in sight-saving classes. In discussing this general

problem, another reliable source maintains that "for reading average print on white paper, there should be at least ten to twenty foot-candles. For newspapers and for ordinary office work there should be at least 20 to 35. For ordinary bench work, such as the work done in school manual training classes, there should be at least 20 to 50 foot-candles, depending upon the nature of the work. Much machine work, cooking and other household tasks, many games, work on hobbies, and many other activities fall in this area. Drafting and other accurate drawing needs at least 30 to 50 foot-candles. Sewing requires more light—not less than 50 to 75. This amount is needed also for fine assembly, such as putting together watches or other articles made up of many small parts.

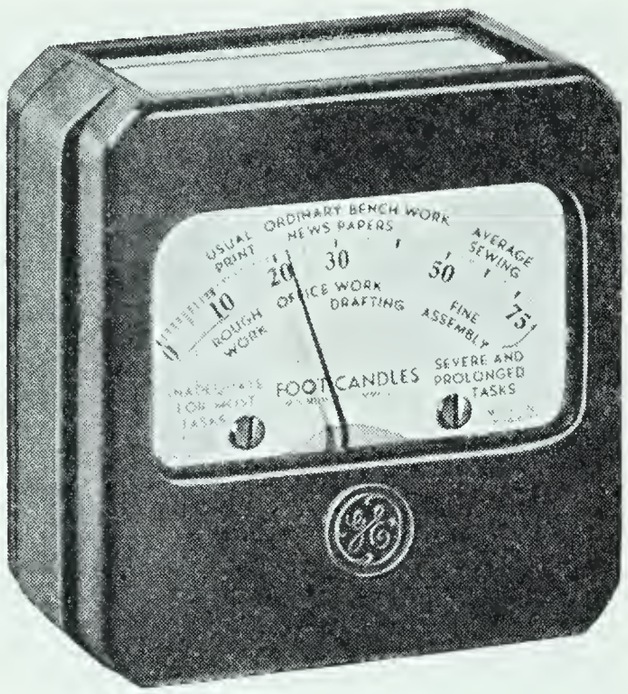


Courtesy General Electric Company

A foot-candle of light is the intensity of illumination obtained on a surface one foot away from a standard candle. If the area of the surface is one square foot, the total light energy it receives is one lumen.

"Severe and prolonged tasks should have even more light. This is especially true if seeing must be quick as well as accurate. Several hours' work on a stamp collection, in which identification of many stamps depends upon distinguishing small details, also falls in this classification."

It is a simple task to check the illumination in various parts of a room with a light meter. Light meters are commonly part of the school science equipment, and many people have them for use in photography. It is sometimes possible to borrow one from the local power-and-light company. A light meter held properly where you ordinarily hold a book or newspaper when reading enables you to determine whether or not the illumination comes up to the minimum desirable for this activity. The usual type of light meter is really a photoelectric cell which generates an electric current when light falls upon it; the current size depends upon the intensity of the light striking the light-sensitive surface of the meter. Ordinarily, the scale of the instrument is graduated to indicate the intensity of the light in terms of foot-candles of



Courtesy General Electric Company

At the top of the light meter is a light-sensitive cell. To find out how many foot-candles your reading matter receives, hold your book in the usual reading position, and then place the meter on the book so that the cell is parallel or on the same plane with the book. Do not let your head or shoulders obstruct the light to the cell.

illumination rather than to show the size of the current. Foot-candles measure light as degrees measure temperature. Even in winter we can provide the 68 to 70 degrees necessary for comfort, but we do not yet know the answer to 300-500-1,000 foot-candles. What usually impresses one when for the first time testing the lighting of a room is the great difference in the illumination of different parts of the same room.

Before you start measuring the illumination in your home, see that all controllable conditions surrounding the lamp to be tested are as favorable as possible. Are both the bulb and the shade clean? Do you have the best available shade on the lamp—a large one, lined with white? If it is a reading lamp, is it placed so that your book receives the full benefit of the light? The standard position for such a lamp is about 30 inches from you. Are your eyes protected from the source of light? When all these factors are adjusted as well as possible, apply the test with the light meter. Compare the reading with the value given for the same conditions in the following table.

	Foot-candles
Reading	
Prolonged periods with fine type	20-50
Ordinary	10-20
Sewing	
Fine needlework on dark goods	100 or more
Prolonged average sewing	50-100
Prolonged sewing on light goods	20-50
Ordinary sewing on light goods	10-20
Writing (ordinary)	10-20
Card playing	5-10

Children's study table	20-50
Dining-room, if used for ordinary reading or writing	10-20
Kitchen	
General	5-10
Local (at work counters and sink)	10-20
Bedroom	
General	2-5
Bed light	10-20
Dresser, vanity and dressing-table mirrors	10-30
Sewing machine	20-50
Bathroom mirror	10-30
Children's playroom	
General	5-10
Local	10-20
Stairways and stair landings	2-5
Workbench	10-30
Ironing machine, ironing board, and laundry trays	10-20

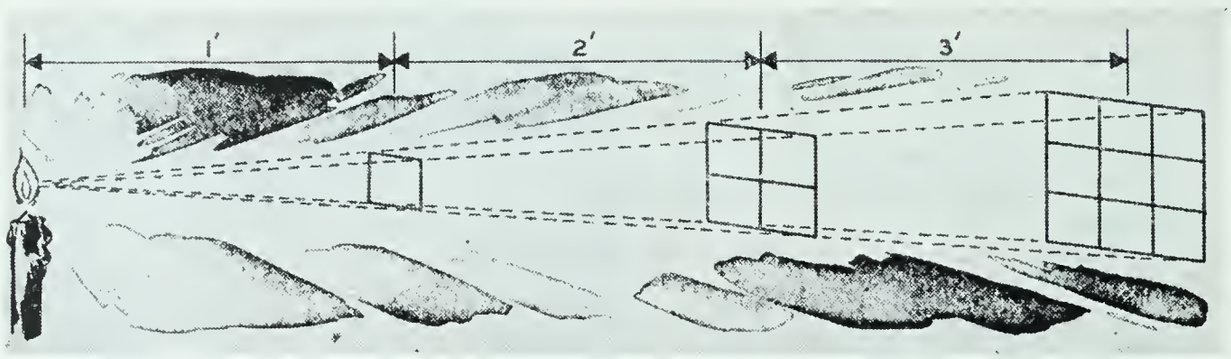
A range is given to allow for variation of local conditions and in individuals. Larger values, however, should not be considered maximums—merely minimums for conditions obviously worse than average.

With a light meter it is also easy to check the so-called Inverse Square Law of Illumination—namely, *the amount of light a body receives is inversely proportional to the square of its distance from the source of light.* Accordingly, an object 10 feet away from a light receives illumination only one-fourth as intense as an object 5 feet away. This should be remembered when lamps are being located in a room. The Inverse Square Law relationship is a valuable one, but it does not apply unless the distance is at least five times the maximum dimension of the light source or fixture. In many instances people have tried to apply this relationship 2 or 3 feet from fluorescent units which may be 4 or 5 feet in length and 2 or 3 feet in breadth. In these instances, of course, the Inverse Square Law does not hold. A 100-watt incandescent lamp is about a 90 candle-power light source. Since the illumination decreases as the square of the distance, or according to the formula

$$\text{foot-candles} = \frac{\text{candle power (C.P.)}}{\text{distance in feet}^2\ (d^2)}$$

3 feet from a 100-watt lamp the illumination measures only about 10 foot-candles:

$$\frac{90}{3^2} = 10$$



Courtesy General Motors Corporation

The illustration shows the law of illumination. The amount of light on a surface 1 foot from a standard candle is 1 foot-candle. At 2 feet from the candle, the same amount of light must illuminate four times the area; hence, the intensity is cut to one-fourth of a foot-candle. Give similar explanations for distances of 3 feet and 4 feet.

What is the illumination at a distance of 6 feet from the same lamp?

At best it is extremely unlikely that the eyes of any two people in a room will receive the same amount of light energy. With proper planning it should be possible to insure adequate lighting in all parts of the room and particularly around the furniture groupings where close work is likely to be done. Light from a lamp should approach one from the rear so that the source lies outside of the line of vision and from the left of right-handed persons to throw the shadows of the hands away from the work being done.

• WHAT KIND OF LIGHT?

Light on the object we are looking at is illumination—that is good; direct light in the eye is glare—that is bad. Glare results from a number of causes which can be controlled so that glare is avoided, resulting in the production of soft, diffused light. We want enough light, to be sure, but misplaced brightness also produces glare. The quality of light, its amount, and its proper distribution all help determine whether lighting is good or poor.

First choice in light for illumination is the sun itself. In regard to the quantity of light, our past history has been one of competing with darkness, but now that we can provide 50 to 100 foot-candles with ease, we may say that we are actually competing with daylight. In order to make the most of daylight in your home, use light-colored window shades. Do not use dark, heavy drapes or curtains over windows. Where draperies are hung, arrange them so they cover the casing and not the window. Place desks, tables, work-

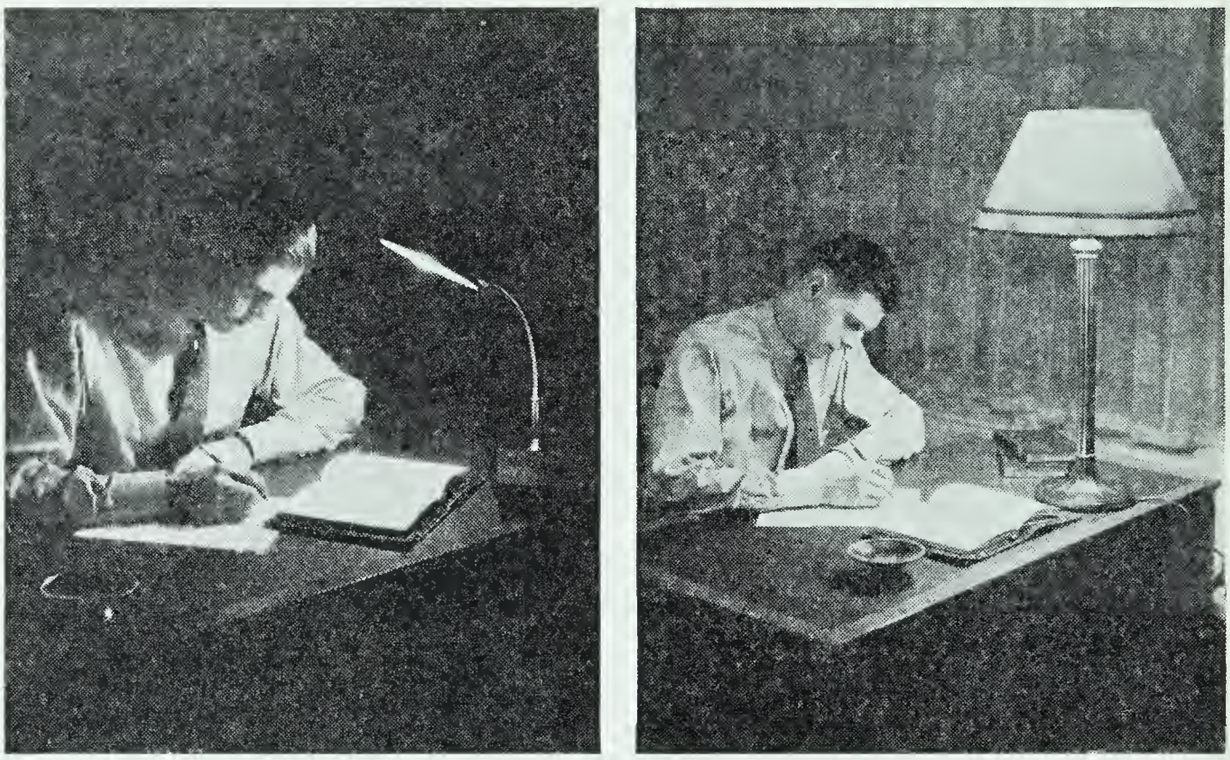
benches, and reading chairs where they can be lighted by the sun.

Take advantage of the psychological effects of colors so as to make the most of daylight. For instance, rooms with northern exposures, which receive very little direct sunlight, are made to seem lighter and brighter if the walls are finished in "warm" colors, such as peach or yellow. Rooms with southern exposures or any rooms which receive a great deal of direct sunlight can be made to seem cooler and less glaring by the use of such "cool" colors as blues and greens. The darker the paint on your walls and ceilings the more light you need for good seeing. Lightness of ceilings is particularly important where modern upward-shining indirect lighting is used. Paint finishes on walls and ceilings should have dull surfaces. By diffusion they produce an easy, comfortable light, while glossy finishes cause glare.

The use of frosted lamps helps considerably in the production of soft, diffused artificial light. All lamps should be shaded further to reduce glare and soften shadows. Diffusing-glass or plastic bowls are antiglare devices; so are shades made of parchment paper or light-weight, light-colored silk. The shading should be sufficient to conceal the outlines of the lamp bulb or whatever bright source is used.

Glare may be defined as misplaced brightness. When it occurs in the field of vision, it interferes with the vision and causes discomfort, annoyance, or eye fatigue. As a protective measure the pupil of the eye contracts in the presence of glare and admits less light to the interior of the eye than it would if the interfering brightness were absent. The sensitivity of the retina, and hence of the eye in general, is less when glare is present. Unfortunately, glare is one of the most common faults of lighting. However, it is possible to provide illumination of high intensity and yet avoid both direct and reflected glare. To accomplish this, general light sources should be hung rather high whenever possible, in order to keep them out of the normal line of vision. Shiny or glossy surfaces on walls, ceilings, and woodwork are objectionable because they cause reflected glare.

The Illuminating Engineering Society has published specifications which are followed by many manufacturers of lamps. The I.E.S. tag on a lamp means that the lamp conforms to these specifications; it is also an assurance that certain safety requirements have been met. I. E. S. Better Sight Lamps give generous amounts of good-quality light when used with bulbs of specified size. In the accompanying comparison of one of these lamps with an older-type



Courtesy General Electric Company

Good lighting means improved study conditions and greater conservation of precious eyesight. Do the following statements describe the lamp on the left or the one at the right? (1) The lamp is too low to cast light over the whole desk area. (2) Glare is created by light thrown in one small space. (3) The diffusing bowl shields the bulb and reduces glare. (4) The wide opening at the top throws ample light to the ceiling for general illumination. (5) A special white lining inside the shade reflects light.

lamp, attention is centered upon noteworthy features which help in judging the merits of various devices for illumination.

A rather recently developed material called Polaroid glass is being used to improve the quality of illumination by reducing the amount of glare. The story of how a desk lamp equipped with a Polaroid filter tends to free the eyes from glare also presents one of the strongest arguments for the wave theory of light. Polaroid glass actually consists of a lamination between pieces of glass of a flexible sheet of plastic in which are embedded about a thousand billion crystals to the square inch. These crystals all lie parallel to each other and act like a strainer or filter for light waves. They allow to pass through only those light waves which are vibrating in one particular transverse plane. Ordinary light consists of waves vibrating in all possible planes. One disk of Polaroid glass rotated over another forms a combination which is transparent like ordinary glass when the axes of the crystals are parallel. It is almost opaque when the axes of the crystals in the two disks are crossed one with the other. Can you continue this explanation to show



Courtesy New York Museum of Science and Industry

These views are of a dangerous curve as seen without and with the aid of Polaroid sunglasses. Polaroid glass eliminates glare and makes the lettering visible.

that there is nothing mysterious about this action of the two pieces of Polaroid glass?

When light is reflected from the shiny surface of such things as paper, asphalt or water, the surface itself acts something like a disk of Polaroid glass. It arranges the random vibrations of ordinary light into regimented parallel vibrations like flat stones skipping from water. If a desk lamp is arranged with a Polaroid filter in it so that the light vibrations strike the paper at right angles to the surface instead of parallel to the surface, the light cannot skip off as glare. When there is no glare, it is easier to see.

Polaroid glass is now being adapted to desk lamps, sunglasses, automobile headlights, camera filters, advertising displays, three dimensional pictures, industrial strain testers and many other devices. The strain testers locate flaws in transparent materials and help engineers design structures of great strength. The ways in which polarized light is being applied are constantly increasing.

There are several systems for providing artificial illumination. Lighting is called *direct* if all the light is directed downward from the source, *indirect* if it all goes upward from the lamp, *semi-indirect* if, as in the I.E.S. lamp, light travels from the lamp in both directions but mostly upward, and *semidirect* if a larger percentage of the light travels downward than upward from the source. In general diffused lighting, the quantities of light in both directions are about equal.

Direct lighting from high-brightness filament-lamp sources is considered unsatisfactory for general illumination, but when diffused properly it is sometimes desirable where a high concen-

tration of light is needed over a particular area. Many fluorescent systems are direct but have high diffusion. Because the fluorescent lamp is a low-brightness source, it need be shielded only from direct view. Indirect lighting produces the least annoying shadows and is highly desirable for general illumination up to about 50 foot-candles. Above this, ceiling brightness becomes so great that it becomes an annoyance factor. Indirect lighting costs more than the other types to operate. When cost as well as quality of light are taken into consideration, semi-indirect illumination is usually the most practical for ordinary purposes.

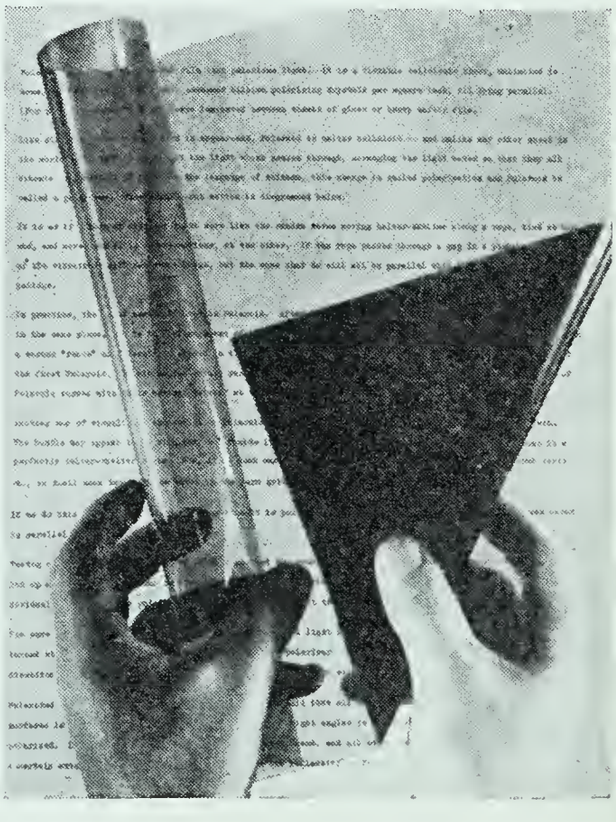
• FROM ELECTRICITY TO LIGHT

The oldest device for obtaining light from electricity is the arc light. Arc lights are still used in some localities for street lamps. They are also used to a considerable extent in projectors because of the brightness of the light. This brightness coupled with certain other disadvantages make the arc unsuitable for lighting the interiors of homes and other buildings.

The arc is lighted by bringing together two carbon rods in a circuit of sufficient voltage (about 50 volts or more) and then separating them about a quarter of an inch. Enough heat is produced by the current during the few moments when the rods touch to vaporize some of the carbon. This vapor serves as a conductor, keeping the current flowing when the carbons are separated; the electricity furnishes the energy to keep the vapor intensely luminous. The "other disadvantages" referred to above are due to the vaporization of the carbon. After a while the carbon rods must

You can see perfectly through several thicknesses of a Polaroid sheet if the optical slots in the sheets are parallel, as they are in the roll at the left below. But when the slots of the material are crossed, as they are in the fold at the right, no light passes, and you cannot see through.

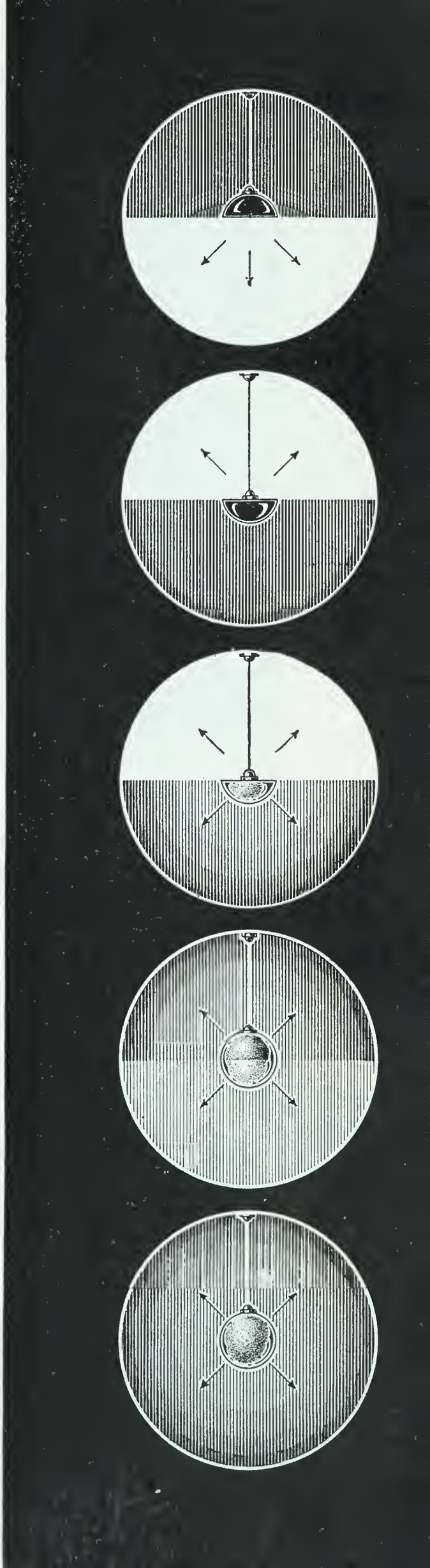
Courtesy Polaroid Corporation



be replaced, and rather expensive mechanism is necessary to keep them the correct distance apart while the lamp is being used. Moreover open arcs tend to be noisy. They are unsurpassed for searchlights and for projection systems in theaters.

Edison was the first to make a practical lamp which uses a thin strip of material whose resistance is great enough to change electricity into light. Others had tackled the problem before him and realized that it consisted of three parts. As far as the lamp itself was concerned, two difficulties were met: (1) finding a filament which would not melt or evaporate too much when its temperature was raised to incandescence; (2) keeping it from burning up

KINDS OF LIGHTING



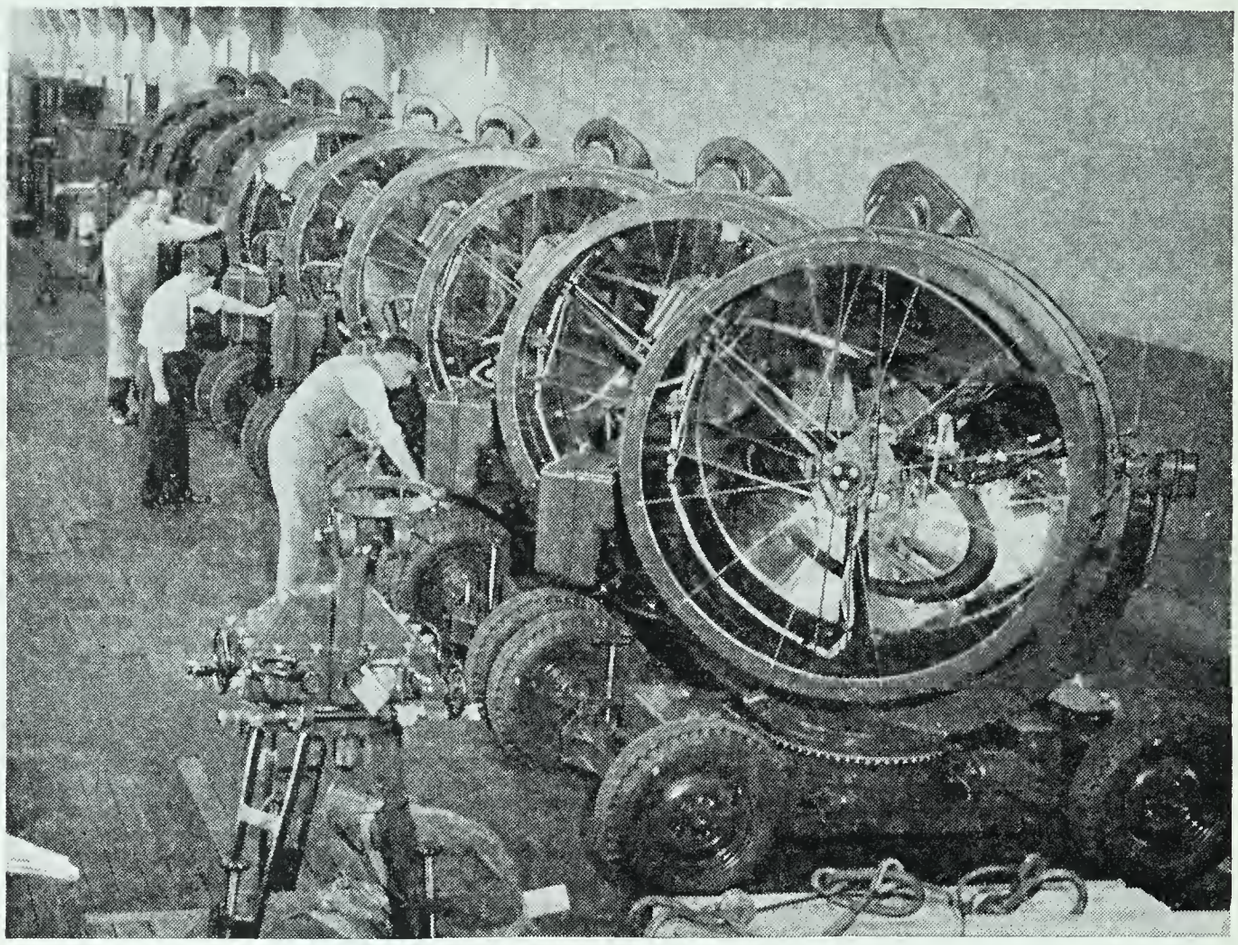
Direct: Reflector directs almost all of the light to a particular area without redirection or reflection.

Indirect: Here 90 to 100 per cent of the light rays strike the ceiling and are reflected down into the room.

Semi-indirect: Reflector directs 60 to 90 per cent of light to ceiling and side walls; the rest is directed downward.

Semidirect: Reflector directs 10 to 40 per cent of the light upward and 60 to 90 per cent is directed down into the room.

General diffusing: Light is controlled by a reflector so that all of it is evenly directed, as shown in this sketch.



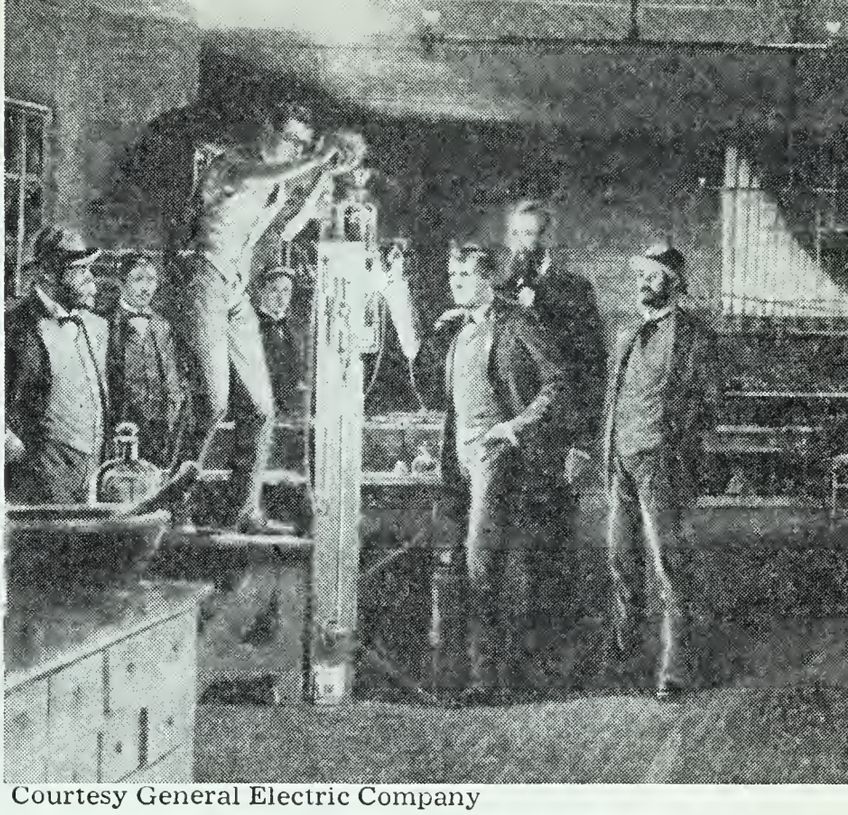
Courtesy General Electric Company

This row of antiaircraft searchlights is ready for use in searching the clouds for enemies of America. Each searchlight is sixty inches in diameter, and the light produced by the carbon arc at the focal point is of 800,000 candle power. Their beams cut the sky for a distance of five and one-half miles. They are mounted on wheels for swift movement.

even if it did not melt. The third complication arose because the electrical generators then known failed to maintain a fairly constant electric pressure (voltage) as the amount of current (amperage) being consumed varied. Obviously there is a great variation in the number of electric lamps turned on at different times and hence in the amount of current needed. If the voltage wavers, the current through the lamp wavers producing a "flicker" effect.

After a number of years of experimentation, Edison succeeded in solving all three parts of the problem. He invented a new type of generator to provide the current, and in 1879 he built a practical lamp. His early lamps had carbon filaments made by baking ordinary thread until it charred. Better carbon filaments were later made, in turn, from paper, bamboo strips, and cellulose squirted into a filament much as rayon is today. Since ordinary burning does not take place without the support of oxygen, Edison protected his filament against burning by enclosing it in a glass

bulb from which he pumped the air. However, the filament slowly oxidizes over a long period of time, because we have no way of making a perfect vacuum. Edison's incandescent lamp is the best known of the many inventions which have earned him top ranking among the world's great inventors.



Courtesy General Electric Company

In his laboratory in 1879, Thomas A. Edison lighted his first practical incandescent lamp. The world thus gained a new, wonderful source of artificial light.

Great improvements have been made in the incandescent lamp during the last few decades. Tungsten, which has the highest melting point among the metals, has been substituted for carbon. When Dr. William D. Coolidge, of the United States, invented a method for making tungsten ductile so that it could be drawn into fine wire, its use for lamp filaments became universal. Since then, Dr. Irving Langmuir, also an American, discovered that tungsten filaments last much longer if the bulb is filled with an inactive gas. Evaporation of the tungsten during incandescence tends to destroy the filament and blacken the lamp. Evaporation was the chief cause of failure in Edison's early lamps and still is in vacuum lamps today. A mixture of argon and nitrogen is now generally employed in electric lamps to slow down this process of evaporation.

Manufacturers of electric lamps tell us that our best interests require them to make a compromise between long life and low-operation cost. In general, measures which increase the life span of the filament also increase the cost of operation—they increase the amount of electricity used to produce the same quantity of light. Low efficiency had been the chief objection to carbon-filament lamps, since these lamps did have long life in their favor. An important advantage of the tungsten-filament lamp over the carbon-filament lamp is its higher efficiency. As always, efficiency means the ratio of output to input. The output of light in an electric lamp is stated in *lumens*. The lumens given off by a light source can be shown to be 4π times its candle power. The input in an electric lamp is measured in watts. A carbon-filament lamp has an efficiency of only about 4 or 5 lumens per watt. The highest

efficiency for tungsten vacuum Mazda lamps is 10 or 11 lumens per watt. For gas-filled Mazda lamps, the efficiency ranges from 10 or 11 up to about 17.5 lumens per watt for larger lamps for general lighting. Special lamps for airports and projectors run to 25 or 32 lumens. The efficiency of a 100-watt Mazda lamp of the type ordinarily used for home lighting is about 15 or 16 lumens per watt.

Manufacturers report that it is possible for them to build tungsten-filament lamps which would last longer than those now on the market but advise that the present ones are designed to give us the most light for each dollar spent. The photo-flood lamp, which is used in photography to provide extra illumination, is a good example of a filament lamp which is meant to work very efficiently, but only for 2 to 10 hours. Ordinary filament lamps are designed to give 750 to 1,000 hours of service.

The fluorescent lamp, which made its appearance in 1938, is rapidly gaining in popularity. One of the most important reasons for its quick adoption is its relatively high efficiency—44 lumens per watt for the 40-watt white fluorescent lamp as compared to about 16 lumens per watt for the ordinary 100-watt incandescent lamp. As an energy transformer, it transforms more of the current into light and less into heat than do other electric lamps. It generates less than half the heat of an incandescent lamp and is never too hot to the touch. Heat production in a lamp is wasteful and adds to our discomfort in hot weather, but no lamp yet invented produces light without producing some heat.

Equally important in the quick adoption of fluorescent lamps is the fact that they are a linear source of low-brightness permitting direct, semidirect, and direct-indirect lighting systems which make 50 to 200 foot-candles practical. Another factor favorable to the increased use of lamps of this type is their ability to produce a color quality very similar to daylight. It is often advantageous, as when selecting articles of clothing, to have artificial light in which color tones do not differ much from their appearance in sunlight.

In operation, fluorescent lamps resemble arc lamps more than they do ordinary incandescent lamps. They involve electric discharge and have no filament. The discharge generates a large proportion of ultraviolet rays (as well as some visible light). These rays are produced by high-voltage current discharged through the gas enclosed in the lamp. Ultraviolet rays are similar in nature to visible light rays except that their wave lengths are much shorter,

and ordinarily they do not enable us to see objects upon which they fall. However, ultraviolet rays do cause certain substances upon which they fall to fluoresce—that is, to glow and give off visible light. Fluorescence takes place when invisible ultraviolet rays, instead of being either reflected or absorbed, set up in the atoms of a substance an excitement which creates a longer wave length—a wave length of some visible color. In other words, "radiation" of short wave length (ultraviolet light) disappears and radiation of longer wave length (visible light) replaces it.

The slim glass tube of the fluorescent lamp encloses a small amount of argon at low pressure and a trace of mercury. When the current is turned on, the argon serves as a "starter," and a feeble blue light and invisible ultraviolet rays are generated in the tube. As the ultraviolet radiations strike the fluorescent powder, such as calcium or magnesium tungstate, with which the tube is coated, an energy transformation takes place and visible light is given off. In other words, invisible ultraviolet energy is absorbed by the mineral, which then rebroadcasts the energy on wave lengths in the visible part of the spectrum. With the proper coating, rich, colored light for decorative effects or white light for general illumination may be obtained.

The forerunners of the fluorescent lamp are the electric gas-discharge lamps. These have been in use for some time as neon signs for advertising, sodium-vapor lamps for lighting highways, and mercury-vapor lamps for industrial lighting, for use in photography, and for killing bacteria. Other gas-discharge lamps have been developed for special purposes. These lamps are characterized by their brilliant colors and high efficiency. In all of them we find the same science principle being applied—namely, that visible light may be produced by having electrical discharges travel through a tube containing a small amount of gas under small pressure. Glowing neon gas gives red light, argon gas blue light, helium gas white light, sodium vapor yellow light, and mercury vapor green light. Different shades can be obtained by coloring the glass, by employing other gases, and by using mixtures of gases.

Since sodium is a solid and mercury is a liquid, the sodium-vapor and mercury-vapor lamps must have some arrangement for vaporizing these materials when the lamp is turned on. One type has a tungsten filament to furnish the heat which vaporizes the mercury or sodium. The vapor then glows and takes most of the current since it is a better conductor of electricity than the wire. Sodium-vapor lamps also contain a little neon to assist in the lighting

process. This explains why they give red light for a time before emitting their characteristic soft yellow light. This yellow light is very desirable for lighting bridges and highways, because of its caution value and its high efficiency. No additional advantages exist; it is a mistaken belief that sodium-vapor lamps penetrate fog unusually well.

Exercises for Problem Study and Review

1. List the reasons why electric lighting displaced flames as the dominant source of artificial light.
2. Do you think electricity should be made available to all American families? If so, how do you think this should be taken care of in remote areas where the power companies say the cost of distribution makes the service of electricity unprofitable to them?
3. In what ways has the process of becoming civilized placed greater strain upon man's eyes?
4. Compare indoor and outdoor illumination as to intensity. Define the intensity unit used.
5. Is the intensity of light on this page adequate for the reading you are now doing? How can you check to make sure?
6. On what principle does a light meter work? What are some other applications of this principle?
7. What factors other than intensity determine whether lighting is good or poor? Explain.
8. How is "Polaroid" used to reduce glare? Explain its action.
9. What is semi-indirect illumination? Compare it with direct and indirect lighting as to cost and quality.
10. Compare the science ideas underlying the production of light in arc lamps with those seen operating in incandescent filament lamps and those at work in fluorescent lamps.

Problem 4: How do we produce and use other radiations related to light?

• RELATIVES OF VISIBLE LIGHT

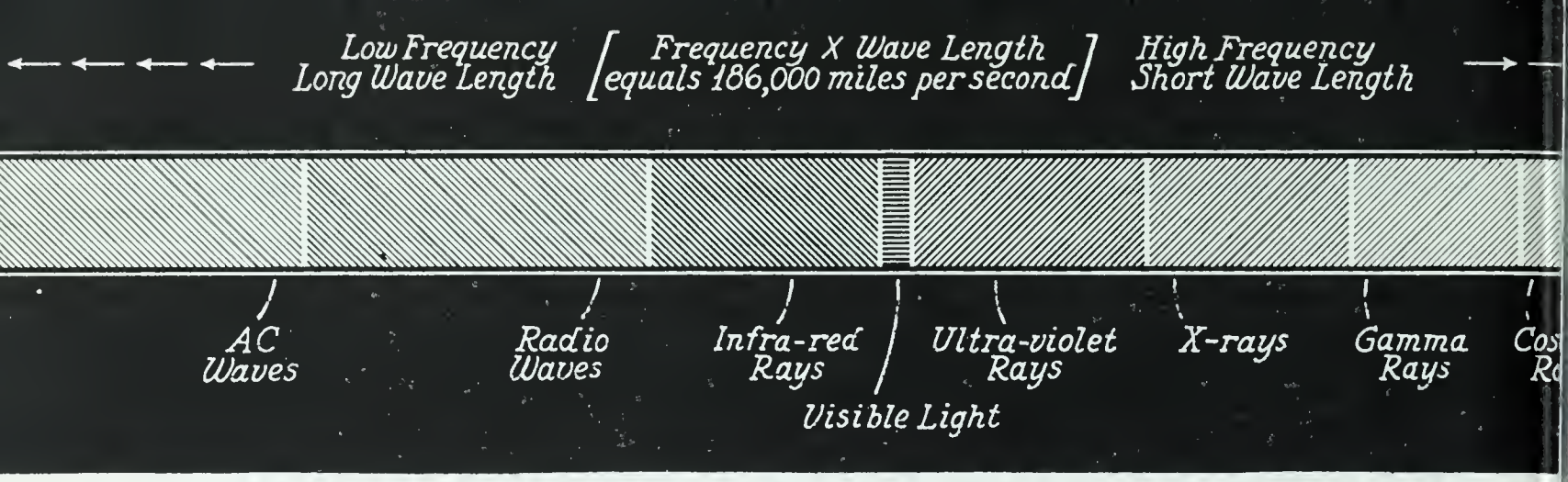
We and the earth upon which we live are under a continuous bombardment which streams toward us from space in all possible directions. Evidently we are none the worse for being under constant siege, but one cannot help wondering how much is miss-

ing from the picture of this world which our sense organs give us. Until early in this century when scientists discovered the presence of these radiations and built a special instrument to register when they strike, their existence was unsuspected. We have no sense organ to detect their passing. "Passing" is indeed the correct word, since they go through our bodies as if we were sieves. In fact, they can travel for a considerable distance through anything they strike. Experiments show that they can penetrate 200 feet of water or 18 feet of lead before being stopped. Beyond the fact that these rays enter the earth's atmosphere from outer space, their origin remains a mystery.

Ask the scientist what they are, and he might satisfy your curiosity a little by telling you that they are *cosmic rays.* Press him to explain further what cosmic rays are, and he might reply that they are in some respects similar to X rays or ultraviolet rays or even ordinary light. He knows that these forms of energy, as well as a few others, are all members of a family of radiations which he calls the *electromagnetic spectrum.*

Our eyes respond to only about one-sixtieth of the known range of the electromagnetic spectrum. However, some of the other radiations also affect us directly. All radiations which are absorbed make us warm; certain infrared rays are detected by receptors in our skin. X rays and gamma rays destroy skin or other cell tissue which is exposed to them for more than brief periods. X rays and ultraviolet rays also make some objects glow. You will recall the application of this property of ultraviolet rays in fluorescent lamps. Our own teeth, many minerals, kerosene, numerous dyes, and some other familiar objects also fluoresce in ultraviolet light. Other members of this family of radiations require complicated devices for their detection. The radio receiving set is one of the mechanisms which aid and extend our senses so that we can become aware of the invisible energy which fills our environment.

We have described visible light, the most familiar of these radiations, as if it were a form of energy traveling in waves, apparently needing nothing to travel on, for it comes to us through the nearly perfect vacuum which we call space. However, there is evidence that it exerts a minute pressure on the surfaces which it strikes—just as it would if it were made up of tiny particles. In the fluorescent lamp, ultraviolet light, a near relative of visible light, definitely seems to make the coating of the lamp glow by bombarding it with tiny packets of energy. As a matter of fact, when Shake-



Members of the electromagnetic spectrum differ in wave length and frequency. As far as is known, they all travel at about 186,000 miles a second.

speare was writing his plays, it was rather generally agreed among the scientists that light consisted of tiny granules. Christian Huygens had stated in 1678 that light was a series of waves, but students were more likely to agree with the corpuscular theory put forth by Sir Isaac Newton a few years later. Newton did not agree with Huygens that light was a wave motion, because he could find no tendency of light to bend around corners as waves do, according to our experience with sound. Besides, it was necessary for the followers of the wave theory to invent something for their waves to spread through. They called it "luminiferous ether," but no one could prove that it really existed. Today scientists do not accept in full the view of either of these early pioneers. The evidence seems to indicate that the hypotheses of Huygens and Newton were both partially correct. At present, the physicist finds himself in the somewhat contradictory position of having to use the viewpoint of Huygens to explain certain phenomena and that of Newton to account for others. Whether light is a wave or a shower of energy packets called photons is somewhat of a mystery. Indeed some are of the opinion that the nature of light and other radiations of the electromagnetic spectrum is such that it involves both wave motion and granular structure. While acknowledging the incompleteness of their knowledge here as elsewhere, scientists place faith in those generalizations which even now increase their ability to explain and to predict and which point the way toward greater understanding in the future. The present wave theory of light is one of these extremely valuable generalizations.

The outstanding difference in the make-up of these radiations of the electromagnetic spectrum is the difference in wave length. The illustration indicates the gradual decrease in wave length as one goes from 25-50-60–cycle A.C. waves in electromagnetic fields at one end to cosmic rays at the other. The range runs from waves which are miles in length to those which are only about one one-hundred-thousand-millionth of an inch long. However, whether it be radio waves, infrared rays, visible light, ultraviolet light,



Courtesy Parke, Davis and Company

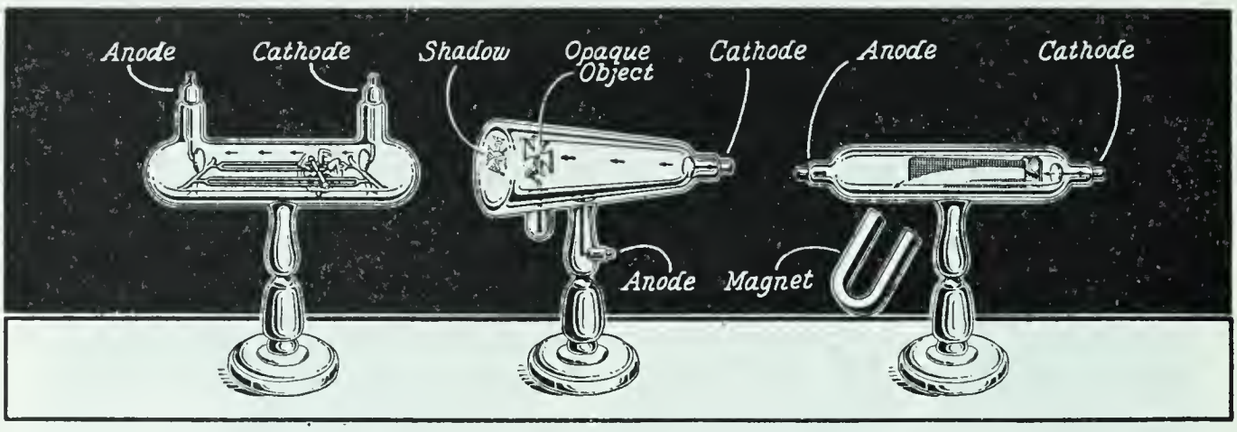
In a dark room Wilhelm Roentgen first sees the skeletal outline of his own hand.

X rays, gamma rays, or cosmic rays, the rate of travel is the same for all—approximately 186,000 miles a second. All travel in straight lines except when reflected or refracted and require no material, such as air, in which to travel. In the last respect they differ markedly from sound, which must have some substance through which to proceed.

Experiments reveal a mathematical relationship which holds true for wave motion—namely, that the velocity is equal to the product of the wave length times the frequency. Frequency is the number of wave lengths passing a fixed point in a second. If one quantity in a multiplication is decreased, the other must be increased if the answer is to remain unchanged. In the radiations of the electromagnetic spectrum, a decrease in wave length is always accompanied by an increase in frequency that keeps the velocity always the same for all members of this family. This constant velocity, of course, is one of the reasons for suspecting that these radiations are also alike in other respects.

• USING THE SHORTER WAVE LENGTHS

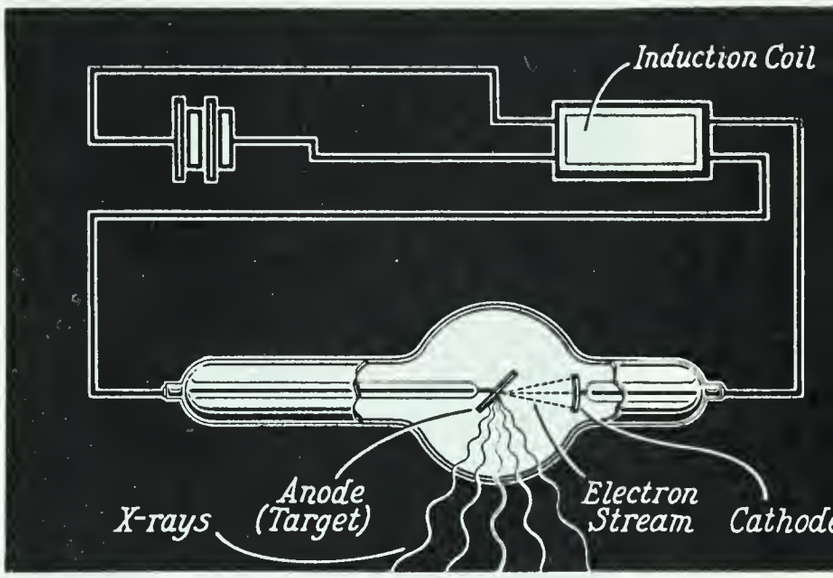
The greatest ability to penetrate is possessed by the radiations of shortest wave lengths. Well-known uses of this property have



Cathode rays consist of a stream of high-speed electrons traveling from the cathode to the anode. The impacts of the electrons on the paddle wheel, causing it to revolve, indicate that they have weight. The manner in which they cast shadows shows that cathode rays travel in straight lines. Their deflection by a magnet reveals that electrons are charged negatively.

been made in connection with the application of X rays to medicine. The taking of "shadow" pictures of bones and other parts of the body resulted from the discovery that these rays penetrate certain substances better than others. While experimenting with electricity, Sir William Crookes, an Englishman, sealed a wire in each end of a glass tube from which he then pumped as much of the air as he could. When he connected these wires to a source of high-voltage electricity, he was surprised to find a pinkish glow in the evacuated tube. In 1895, Wilhelm Roentgen, a German scientist, used a Crookes tube in a darkened room to produce a glow in a piece of cardboard which he had painted with a fluorescent chemical. He discovered the penetrating ability of the X rays when the fluorescent paint remained luminous after he had covered the Crookes tube with a shield of black cardboard. Even though greatly surprised by the continued glow, he did not fail to notice a shadow on the fluorescent surface. Upon investigation he found that the shadow was cast by an object spaced between the cardboard and the Crookes tube. When he held his hand between the Crookes tube and the fluorescent surface, he was amazed to see his own bones silhouetted on the lighted background—the first man in history to view his own skeleton. Since he knew that photographs could be taken with infrared and ultraviolet radiations, he suspected that he might be able to do the same with his newly discovered radiations. Simple experimentation confirmed his suspicions that such photographs were possible.

Modern X-ray tubes, such as the widely used Coolidge X-ray tube, are great improvements over the one used by Roentgen, but



X rays are produced when high-speed electrons strike a heavy metal target set up in their path.

the general method of X-ray production remains essentially the same. The rays which were discovered by Sir William Crookes are now called cathode rays, for they always flow from the negative electrode, or cathode, to the positive electrode, or anode, when high-voltage current is sent through the vacuum tube. Cathode rays can cast shadows, cause a wheel to revolve, and be deflected by a magnet as shown in the illustration on page 540. In 1897, Sir Joseph John Thomson of England suggested that cathode rays are really streams of tiny particles traveling away from the cathode at great speed. He named them *electrons.* Today we believe that the electron is one of a few basic particles out of which the atoms of all matter are composed.

An X-ray tube is really a modified Crookes tube in which a piece of metal such as tungsten or platinum is placed within the vacuum tube to act as a target to be struck by the cathode rays. When the collisions take place, a new form of radiation streams from the target and passes out through the glass tube. This radiation is made up of X rays. They can neither be seen nor be deflected by a magnet and possess great ability to penetrate objects they strike.

The usefulness of X rays depends upon the fact that they cannot pass through some materials as easily as others. Edison invented a means of viewing the result of X-ray penetration without making photographs of it. If an X-ray tube is placed on one side of your hand and a screen coated with fluorescent chemicals on the other side, the bones are depicted on the screen in much darker outline than the surrounding softer parts. Even the softer tissues show variations in the shadows cast, thus making possible some study of them also. The viewing device is called a *fluoroscope.*

Today the applications of X rays extend beyond their usefulness in the diagnosis of fractures and dislocations of bones or in locating objects which accidentally pierce the skin or get into the digestive tract, the lungs, and other parts of the body. They are very valuable in the diagnosis of certain diseases. Many diseases



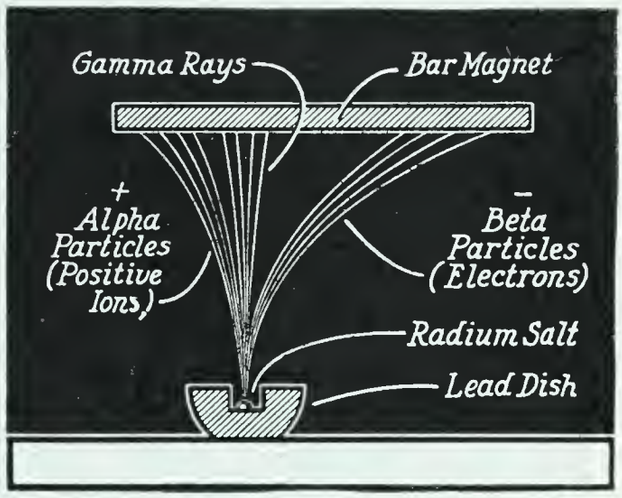
This X-ray photograph shows the bones of the human wrist, hand, and fingers.

of the lungs cause enough change in the tissues so that the diseased part gives a slightly different effect in the fluoroscope or X-ray photograph than does the healthy tissue. X rays of the lungs, for example, may disclose evidences of tuberculosis long before its presence would be revealed by the usual symptoms. This makes possible earlier treatment of such diseases, thus greatly increasing the afflicted person's chances of recovery and shortening the length of time needed for the recovery. If we see our dentist twice a year and the oculist once a year, we should when we are young and susceptible to tuberculosis have a test and examination for that disease on a periodic basis, too. Why not apply our knowledge to the benefit of mankind?

Certain diseases of the bones which may result from inadequate diet, infections in the bone cavities or sinuses, abscesses of the teeth, and tumors in the body may all be diagnosed with the help of X rays. By having certain harmless chemicals such as barium sulfate mixed with his patient's food or drink, the physician can use X rays to study the patient's entire alimentary tract. The chemicals used for this purpose are substances which X rays do not penetrate with great ease. They coat the digestive tract and make it stand out in the X-ray picture. It is likewise possible to examine other organs of the body by using special techniques. The gall bladder or urinary tract may be studied after injecting into the blood some substance which hinders the passage of X rays or after having the patient swallow some similar substance which will pass into the blood stream from the stomach. In either case the blood carries the substance to the part to be studied.

There is no danger to a person who is exposed to X rays for very brief periods. However, there would be danger if one were X-rayed for as long as two minutes. Many of the early workers

with X rays suffered severe and even fatal burns. Some of those not fatally burned developed cancer and died. Oddly enough, X rays are used today in the treatment of certain kinds of cancer. X-ray machines are now quite safe to handle; operators are shielded with lead, one of the metals through which X rays do not readily pass. With the proper shielding, only the areas of the body being examined or treated are subjected to the rays, and these only for such brief periods that there is no danger of harmful effects from the rays. On the other hand, the beneficial effects of X rays save hundreds of lives each year.



Radium and its compounds continually give off positively charged particles, negatively charged particles, and gamma rays, which are much like X rays.

A few of the chemical elements, notably radium, have become useful to man for very special purposes. The reason is that they are made of heavy atoms, some of which are constantly exploding and giving off radiations. Nothing which we can do changes the rate at which this breakup occurs. About 1,700 years are required for half of any given piece of radium to undergo this decomposition. As the radioactive change progresses, the radium is slowly converted into a form of lead. During these changes radium gives off three kinds of rays—namely, alpha, beta, and gamma rays. The alpha rays are streams of positively charged particles. They are easily stopped, as, for example, by a sheet of paper. The beta rays, like the cathode rays of the Crookes tube, are made up of electrons. They are smaller but travel faster than the alpha particles and have somewhat greater penetrating ability. It is the gamma rays which have remarkable ability to penetrate. Like X rays, they do not appear to be streams of particles but rather seem to be true rays with wave motion. The gamma rays have shorter wave lengths than X rays and consequently have greater penetrating ability. Otherwise the two rays are very similar. Both have marked effect upon living cell tissues which absorb their radiant energy. Fortunately, they have a selective action on the tissues. For example, they will pass through healthy tissues but destroy or slow up the growth of cancer tissue which lies beneath. The application of

these rays must be in the hands of experts, however, or serious injury may result.

Radium for use in the treatment of cancer is placed in a container, very often a needle, which can be placed in or near the part to be treated with the gamma rays. The difficulties which limit the use of radium in the treatment of cancer are its scarcity and consequent high price and the fact that it is often impossible to get this radium close enough to a deep-seated cancer growth. The application of correct amounts of the radiation requires the knowledge and skill of the expert. *Radiotherapy,* as the treatment is called, is being put to more and more uses in medicine.

Another common application for radium is its use on the hands and dials of luminous watches. A trace of a radium compound is mixed with another substance, such as zinc sulfide, which fluoresces when struck by the radiations from the radium salt. Improper handling of the luminous mixture by workers who applied it to the watches has in the past resulted in a number of fatal cases of radium poisoning.

Radium is active in many ways. It decomposes water, gives a purple color to glass, changes oxygen into ozone, and kills bacteria. It gives off enough heat each hour to melt one and one-half times its own weight of ice. Its salts glow in the dark as well as being able to make certain other substances fluoresce. Radium ores are found in only a few places, and the process of obtaining radium from these ores is a very expensive one. As a result, radium costs many thousands of dollars a gram.

Another band of radiations which are becoming more and more useful to man as he learns more about them are the ultraviolet rays. Their wave lengths vary between the longer ones of visible light and the shorter ones of X rays. There are, of course, no sharp breaks between the adjacent parts of the electromagnetic spectrum, as our man-made classification of it might lead one to believe. Ultraviolet rays are usually produced whenever ordinary light is made. Some sources of light, such as our sun, arc lamps, photo-flood lights, and mercury-vapor lamps, give off relatively large quantities of this "black light" as it is sometimes called. It is the ultraviolet radiations in sunlight that brown the skin and stimulate the manufacture of vitamin D from chemicals called provitamins present in the skin. Since we need an adequate supply of vitamin D for the building of healthy bones and for the prevention of rickets and other bone diseases, it is necessary for us either to get enough vitamin D by exposure to ultraviolet rays or to get it through our diet if we are to remain healthy. Cod-, hali-



Science Service

Performing an operation under a battery of Sterilamps forming a square around the center light. The ultraviolet radiations which these lamps send out spell death to bacteria.

but-, and shark-liver oils are good sources of this vitamin. Certain foods are being exposed to ultraviolet radiation to increase their vitamin content. It is unfortunate that so many persons must spend the daylight hours indoors since ordinary glass windows absorb most of the ultraviolet radiation which strikes them. Because quartz transmits ultraviolet rays freely, hospitals sometimes provide a room with windows of this material. However, the use of fused quartz is limited by its cost.

Overexposure to ultraviolet radiation is very undesirable. We are no doubt fortunate that our atmosphere absorbs a large percentage of the ultraviolet rays which enter it with sunlight. It tends to be harmful to the human eye, snow blindness being one of the extreme cases of such irritation. In excessive amounts it will even destroy the skin. Exposure to direct sunlight or to artificial sun lamps for long periods should be avoided for this reason.

Because of their destructive action on bacteria, ultraviolet lamps generating "middle" ultraviolet are sometimes used as sterilizers. Mercury-vapor lamps are the ones most used for this purpose. The action of the rays is so rapid that under favorable laboratory conditions the more powerful lamps will kill colonies of bacteria within a fraction of a minute. Manufacturers have demonstrated their effectiveness to health authorities as a possible solution to the "common drinking-glass evil" found in restaurants and other public places. Control of air-borne bacteria has, however, been found





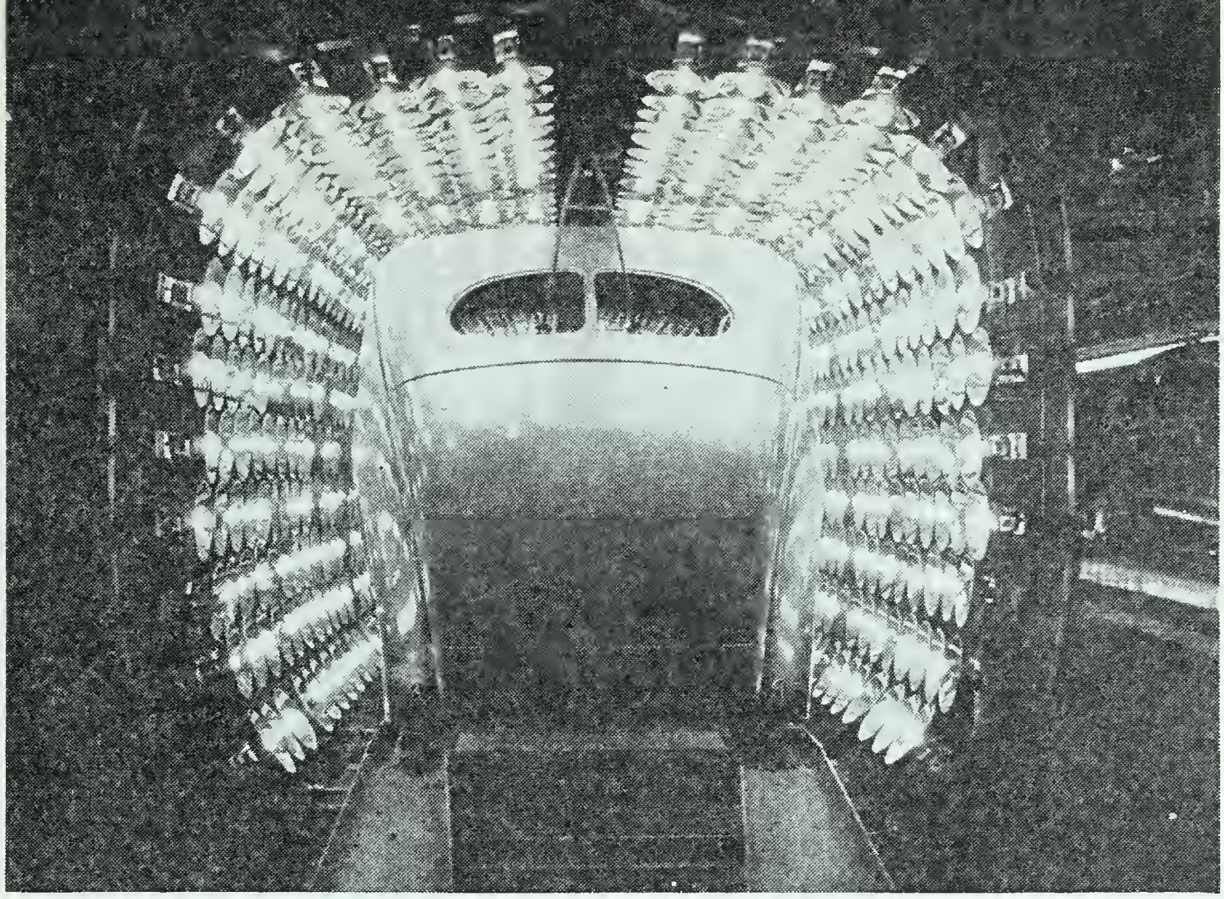
The photograph at the left was made in the ordinary way with visible daylight. The one at the right is of the same scene but was taken with infrared rays, using special film and filter. What advantages can you think of for infrared-ray photography?

a more ready field of application. One watt of germicidal lamp input per 100 cubic feet of air is equivalent in controlling bacterial count to 100 changes of air per hour.

The fluorescence caused in objects by ultraviolet rays is applied in many interesting ways. It is used as a means of identification, as when one suspects he has found a specimen of a certain mineral whose type of fluorescence is well known. Forgeries, alterations in legal documents and paintings, adulteration in foods and construction materials, and blood stains can be detected by the differences in fluorescence under "black light." The plant growth or fungus which causes ringworm gives a bright green fluorescence which makes it easy to diagnose this skin disease. Perhaps you can think of some of the many other ways in which ultraviolet light is used for purposes of identification.

• USING INFRARED RAYS

The longer waves which lie just beyond the limits of visibility are the infrared rays, or heat rays. They, of course, are present in sunlight and are given off by all hot objects. When light strikes an object, a considerable part of it is reradiated as infrared rays. We detect them roughly by sense organs in our skin or more exactly with the thermocouple whose construction was explained previously (p. 245). Sensitive thermocouples will detect a heat source, such as a smokestack, when the latter is several miles distant. Very cold objects such as icebergs can likewise be detected. This is an advantage when the visibility is so poor that the icebergs



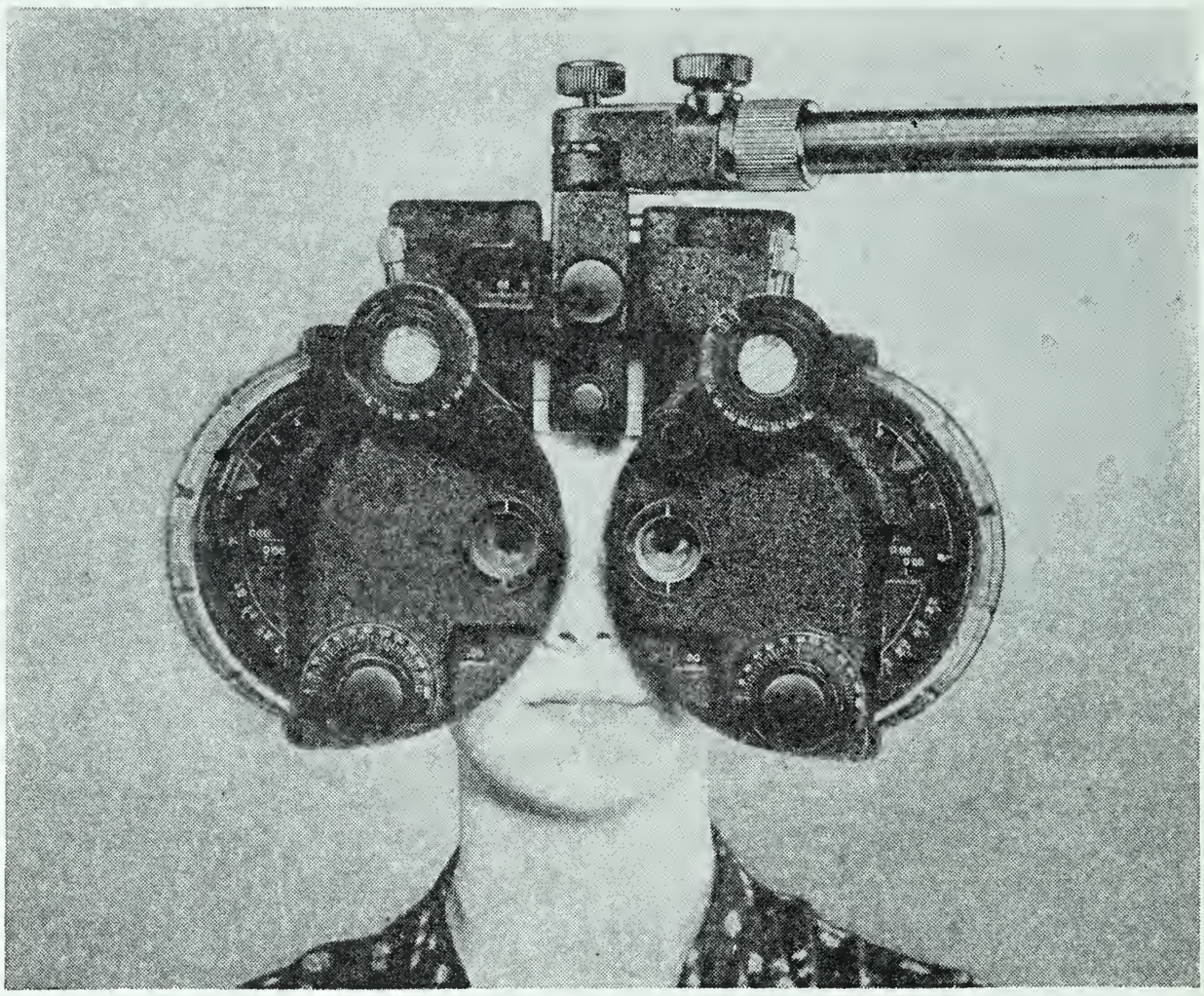
Courtesy Ford Motor Company

Infrared-ray ovens put a quicker, smoother finish on car bodies by heating body metal, thus drying the paint from the inside out.

cannot be seen. How many possible uses for thermocouples could you devise?

Although infrared rays have less penetrating power than shorter wave lengths as far as opaque objects are concerned, they are refracted less by transparent substances and therefore go through such materials as air and glass without being scattered. Since they, too, can affect photographic plates, a very important use for these radiations has been found. With the development of films that are very sensitive to this band of radiations, it is now possible to photograph distant objects on days when a hazy atmosphere would hitherto have made it impossible. Photographs can even be made by infrared in a totally dark room. The most important use of this kind of photography has been developed by the astronomers. They use the spectroscope to analyze the radiations which come from the heavenly bodies in order to find out what materials compose these bodies. By combining infrared photography with spectroscopic study some substances have been detected which could not have been discovered in any other known way.

Incandescent filament lamps are now used in industry for evaporating moisture from materials and for drying newly painted or enameled surfaces. About 90 per cent of the electrical energy used is transformed into radiations lying chiefly in the infrared portion of the spectrum. Radiant-heat lamps are convenient because the lamps can be placed at any angle and the heat directed by reflec-



Acme

This is one of the most remarkable eye-testing instruments ever developed. It contains only thirty-six lenses, but they can be manipulated by oculists and optometrists to obtain 61,060,386,816 prescriptions for eyeglasses.

tors to the place where it is needed. In some instances they reduce the time for drying paint from many hours for ordinary air drying to fewer than the same number of minutes for radiant-heat drying.

Exercises for Problem Study and Review

1. What is the electromagnetic spectrum?
2. In what respects are members of this family similar? How do they differ?
3. Trace the development of the X-ray tube.
4. List the important uses for X rays.
5. Of what importance are radium radiations to man? How are they used?
6. What are ultraviolet rays? Show how they may be either beneficial or harmful.

7. Compare infrared rays with ultraviolet rays in respect to speed, wave length, penetrating ability, and usefulness in photography.
8. To what uses are infrared rays being put?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. When rainbows occur during the morning they usually appear in the west; afternoon rainbows usually appear in the east. Explain.
2. It has been suggested that factories which must be "blacked out" during wartime be equipped with sodium-vapor lighting and blue glass windows. Criticize.
3. Draw a diagram to illustrate why we apparently see the sun for a while when it is really below the horizon.
4. An informed person would usually aim not directly at an object lying under water if he intended to hit it. Explain. What is the exception?
5. Is a beam of light visible while it is passing through a vacuum?
6. Show mathematically that the amount of light which strikes the earth is approximately one two-billionth of the total amount given off by the sun.
7. How do you account for the sparkling colors of a diamond? Why does not a glass imitation sparkle just as well?
8. A woman is sewing at a distance of 4 feet from a 100-watt incandescent lamp. Is this illumination adequate? If not, (1) what size lamp would furnish adequate illumination if she stays where she is? (2) How much closer to the lamp would she have to be in order to get enough light from the 100-watt lamp?
9. Why do artists and photographers prefer to have skylights situated so as to get light from the northern sky?
10. Astronomers tell us to use smoked glasses or several thicknesses of dense photographic film when observing the sun. What is the reason for this? Do you think colored glasses would serve just as well?
11. The moon in total eclipse has a copper color. How would you account for this?
12. Why do fish viewed through the side of a spherical fish bowl seem so much larger than they really are?
13. It is said that a house may be set on fire by sunlight shining through a window and striking a spherical fish bowl. Is this reasonable?
14. Lighting engineers claim, "We have, in many instances, improved upon sunlight." Do you agree? If so, in what respects has improvement been achieved?

UNIT WORD LIST

luminous
illuminated
accomodation
binocular
refraction
complementary colors
interference
convex
concave
real image
virtual image
astigmatism
depth of focus
achromatic
anastigmat
foot-candle
fluorescence
lumen
electromagnetic spectrum
cosmic rays
infrared rays
ultraviolet rays
cathode rays
electron
fluoroscope
radiotherapy
shutter speed

INTERESTING THINGS TO DO

1. Report to the class on the experimentation of Albert A. Michelson, Christian Huygens, Sir Isaac Newton, Wilhelm Roentgen, Marie Curie, Sir Ernest Rutherford, Sir William Crookes, and others whose work related to light.
2. Prepare a historical account of the development of optical instruments.
3. Write an essay entitled "Social Changes Resulting from the Invention of Optical Instruments."
4. Make a collection of electric lamps to illustrate the evolution of this industry and to show the types in use today.
5. Obtain an opaque projector and explain to the class how it works.
6. Check the adequacy of the illumination on each desk in your school room with a light meter.
7. Borrow a stereoscope and demonstrate how it adds a third dimension to a scene.
8. Test your own eyes and those of your classmates for astigmatism and sharpness of vision.
9. Give a talk to the class on "Hints to One About to Use a Motion-Picture Camera for the First Time."
10. Make a series of photographs of actual situations illustrating poor illumination and of others illustrating good illumination. Arrange them as an exhibit on the bulletin board.
11. Find out how the cost of installing fluorescent lamps compares with that for installing incandescent lamps. What does your local power company say about the comparative costs of operation?
12. Make a chart showing the sequence of the electromagnetic spec-

trum, giving information such as the comparative width of each band of wave lengths.

13. Compare an old-type kerosene lamp with the modern form.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. How "Polaroid" can be used to eliminate glare from automobile headlights.
2. The science of color photography.
3. How range finders used on cameras work.
4. Types of color blindness and how they may be detected.
5. Recent methods for making glass more transparent.
6. How lenses are ground for eyeglasses. For telescopes.
7. Problems met the first time in the manufacture of the 200-inch mirror for the Mount Palomar observatory.
8. Differences in the variety of films available for photography.
9. How to build an enlarger for use in photography.
10. The chemistry of photography.
11. How different types of camera shutters work.
12. The electronic microscope.
13. The amount of magnification possible with various types of microscopes and telescopes.
14. How optical glass is made.
15. How the sun produces its light.
16. Three-color and four-color printing.
17. Optical illusions.
18. Olaus Römer's method of determining the speed of light.
19. Use of visible and invisible light for theatrical effects.
20. The construction and operation of reflecting and refracting telescopes.
21. Black art magic.
22. Theories about the origin of cosmic rays.

INTERESTING BOOKS TO READ

Curie, Eve, *Madame Curie.* Doubleday, Doran and Company, New York, 1937. A biographical account of the Curies—Marie and Pierre—and of their scientific researches leading to the discovery of radium.

How to Make Good Movies. Eastman Kodak Company, Rochester, N. Y., 1939. A comprehensive and well-illustrated book containing practical suggestions of procedure in simple, nontechnical language.

How to Make Good Pictures. Eastman Kodak Company, Rochester, N. Y. A standard guide with rules for success in amateur picture-taking. Revised frequently and thoroughly. Understandable by beginners.

Ilin, M., *Turning Night into Day.* J. B. Lippincott Company, Philadelphia, 1936. A translation from the Russian tracing the story of lighting from bonfires to sodium-vapor lamps. Simple, interesting, and explicit.

Teale, Edwin W., *The Boys' Book of Photography.* E. P. Dutton and Company, New York, 1939. Covers all phases of photography with hints on how to get better pictures and have more fun with the camera.

Bombs of London Called Not Unlike U. S. Noises

Psychologist Says Germans Applied to War What Americans Experience Every Day

SAN FRANCISCO (AP)—Scream said. "Think of what happens bombs shrieking down on London when a bomb explodes."

CITY DECIBELS RING TOO LOUD

The League for Less Noise Finds a Lot of It.

Mayor Orders Anti-Noise Test For Taxis, Buses

Tells Police to Rule Them Off Streets Until Engines and Horns Are Quieted

PLAN TO REDUCE ECHO IN STADIUM CONCERTS

$5,000 Is Contributed by the Carnegie Corporation

Standard Musical Pitch Now on Air Day, Night

WASHINGTON, Sept. 14—The National Bureau of Standards has started over its radio station WWV at Beltsville, Md., a continuous broadcasting of the standard for musical pitch—440 cycles per second, for A above middle C.

Broadcast over a frequency of 5 megacycles a second, the pitch may be heard twenty-four hours a day except for some short periods when other bureau programs are being broadcast. The station call letters are announced every ten seconds by voice and Morse code so that persons using the service may be certain they are listening to the right station.

Sound Control Offers Boon to Home-Maker

New Science Reduces Inner Noise by Absorptive Wall Covers and Partitions

DEDICATE ORGAN TOMORROW AT OUR REDEEMER

UNIT EIGHT

SOUND

Story Hour on Records a New Idea

Mayor Revives Anti-Noise War Against Horn-Blowing Autoists

Declares Nuisance Increasing, Orders Strict Enforcement of Ban by Police; Calls on Car Makers Again to Tone Down Strident Warning Devices

'Floating' Walls Prevent Spread Of Home Noise

Spring Clips Between Studs and Plaster Base Called Effective Curb for Sound

Phones in Use Here at New Peak

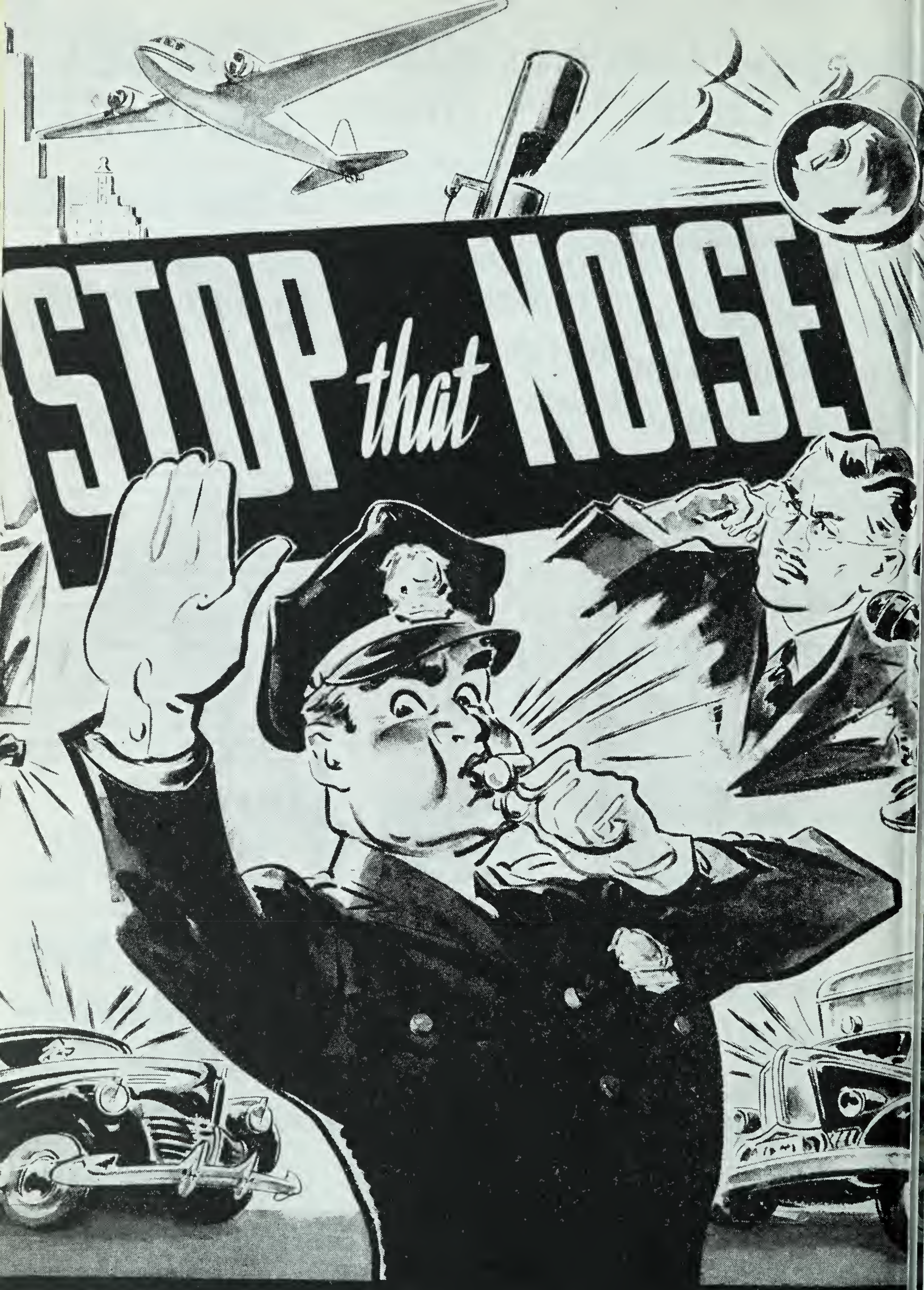
Driver Honks His Way Into Trouble

FM Scores in Midwest; Programs on Three Stations

Frequency Modulation has a long, hard national pull ahead of it ever to compete with regular broadcasting, but if Chicago figures are an indication, the Midwest is ready for FM

mitter by a special telephone line from WBBM. W59C operates a 12-hour daily schedule, noon until midnight. A special orchestra, used only on FM broadcasts, fills an hour or two a day, with transcrip-

STOP *that* NOISE



NOISE ABATEMENT WEEK

Unit Eight

SOUND

Sounds of all kinds are woven into nearly every phase of living. We communicate our thoughts and ideas by means of speech, and by this method we receive a large part of our education. Music plays a role in many of our principal forms of recreation and leisuretime activities—such as dancing; playing musical instruments; attending operas, concerts, and recitals; or just sitting at home listening to the radio or phonograph. Music is a language of the emotions. Recall the feelings you experience when listening to a waltz, a military march, the national anthem, a hymn, or a funeral dirge. Musical sounds bring about reactions which can hardly be produced by written or spoken words.

Noise, too, plays an important part in many aspects of modern life. Engineers depend on sound to a considerable degree to tell whether machinery is functioning properly. Motorists become accustomed to the noise patterns produced by the engines and the body squeaks and rattles of their cars. When a new noise appears, they start a search to see what is wrong. We are just beginning to realize that excessive noise may prove harmful to our mental or physical health. This explains why many cities have waged anti-noise campaigns. Sound conditioning is being increasingly used in offices, apartment buildings, restaurants, hospitals, and school buildings.

All through the ages, man has felt a need for a method of communication that would enable his actual speech to be heard a great distance away—and frequently only by the particular person addressed. For thousands of years this was so impracticable that it was not even thought possible. Then came the discovery of electricity. Men learned how to send electric currents over long wires and to make the electricity operate electromagnets at the other end. The telegraph and the telephone followed. Then men learned how to send electric energy over great distances without the necessity of connecting wires—and radio was born.

Investigation of the unit problems will reveal how man produces, transmits, and hears sound; how he records and reproduces sound; and how sound can be controlled and used.

Courtesy National Noise Abatement Council

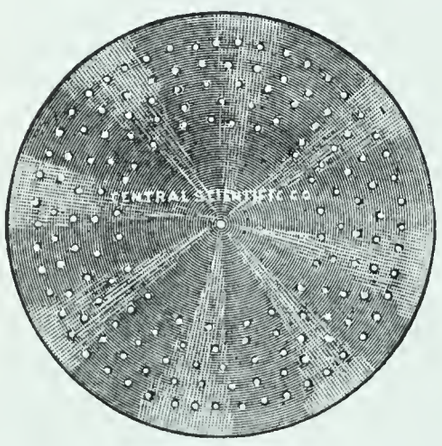
Problem 1: How do we hear?

It has been said that when we see, we see light and when we see light, we see color. It might also be said that when we hear, we hear sound and when we hear sound, we hear intelligible sounds (speech), musical sounds, or noise. What is sound? How does it pass from its source to our ears? How do we hear?

• FROM VIBRATIONS TO SOUND WAVES

The siren disk teaches us a great deal about the nature of sound. Suppose we first rotate the disk at a steady speed while a jet of air is blown against the outer row of regularly spaced holes. The result is a pleasant sound, or *musical tone,* of definite *pitch.* The holes in the next row are also equally spaced but there are fewer of them. When the jet of air is directed against this row, another musical sound is heard, but it has a lower pitch than the first. The same is true of the third and fourth rows of holes—that is, each row contains fewer holes than the preceding one, the holes are regularly spaced, and in every case we hear a musical sound which is lower in pitch than the preceding one. If the speed of rotation is gradually increased and then decreased while the air jet is directed against any one of the rows of holes, the pitch of the sound rises and falls accordingly, giving the *siren effect.*

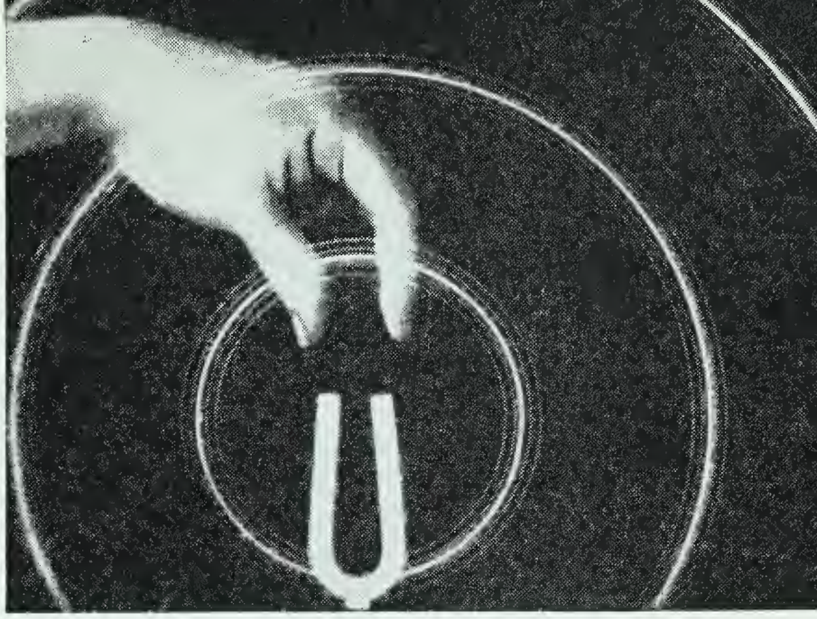
From these experimental facts, we conclude that the regular succession of little puffs of air is what makes the sound produced by the siren disk. Furthermore, we may conclude that the pitch of the sound depends upon the frequency with which the puffs of air pass through.



Courtesy Central Scientific Co.

The siren disk teaches us much about the nature of sound.

There are many indications that sound originates in matter which is vibrating. In the case of the siren disk, it is the air itself which is set into vibration, but sound also originates in vibrating plates, rods, membranes, reeds, air columns, and strings. Nearly all materials resist attempts to twist, stretch, or otherwise deform them. When the deforming force is removed, they are set into vibration, finally coming to their normal positions of rest when the energy dies away. The energy is not lost, how-



Erpi Classroom Film

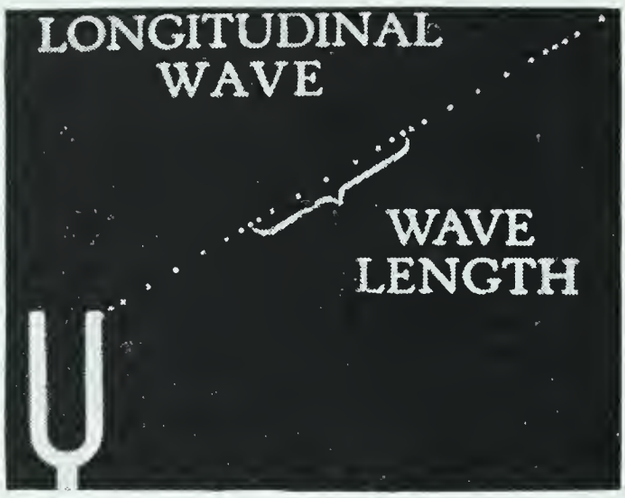
The prongs of the tuning fork move back and forth like a pendulum, sending out waves of pressure variations in the air.

ever, but is passed on to air molecules by the vibrations or is transformed into heat.

If a tuning fork is struck and then plunged into a dish of water, the water is dashed into a spray; if held against a suspended ping-pong ball, the ball is set violently into motion. Evidently the prongs of the tuning fork are vibrating, moving back and forth past their normal positions of rest much as a pendulum swings to and fro. High-speed photographs of violin strings definitely prove that they are set into rapid vibration when plucked or bowed; in some cases, the unaided eye can detect motions of this kind. The "singing" of a mosquito results from the rapid motions of its wings, while the chirping cricket produces sound by scraping its rough legs against its wings.

Vibrating objects set up disturbances in the air around them and send out waves in all directions. In the majority of cases, it is these air waves which carry sound from its source to the ear of the listener. A simple experiment proves that sound is not transmitted through a vacuum—that air, or some other medium, is essential to the transmission of sound. If a small bell or alarm clock is set ringing under a bell jar and the air is gradually pumped out, the sound becomes fainter and fainter. Whether or not the sound becomes completely inaudible depends on how well the vacuum pump works and how well the bell is insulated from the solid part of the jar and vacuum plate.

When the prong of a vibrating tuning fork moves forward, it crowds the molecules of air on that side closer together; or, as we say, it produces a *compression*. When it moves backward, it leaves a space into which the molecules can surge; this is spoken of as a *rarefaction*. Each compression and rarefaction passes along by molecular motion in much the same fashion that a sudden jerk of a locomotive passes from one car to the next throughout the length of the train. Sound waves thus consist of a series of alternately increased and reduced pressures. It is important to note that the molecules themselves do not move from the source of the sound

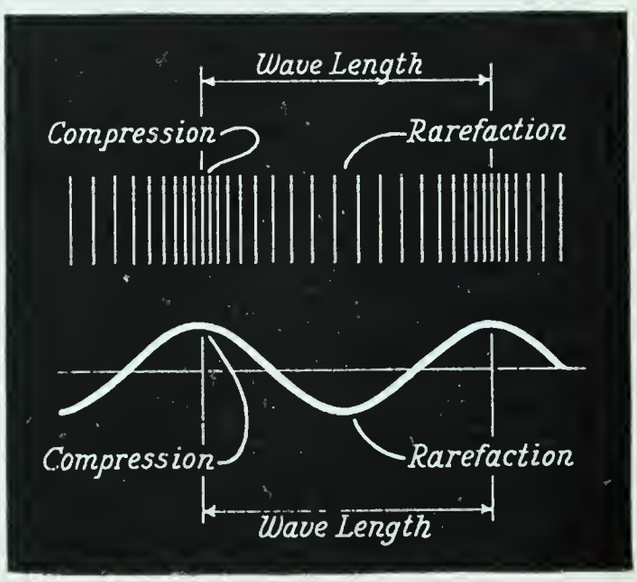


Erpi Classroom Film

to the ear of the hearer; they move back and forth through very small distances as they crowd together and spread apart in transmitting energy from the vibrating object to the ear.

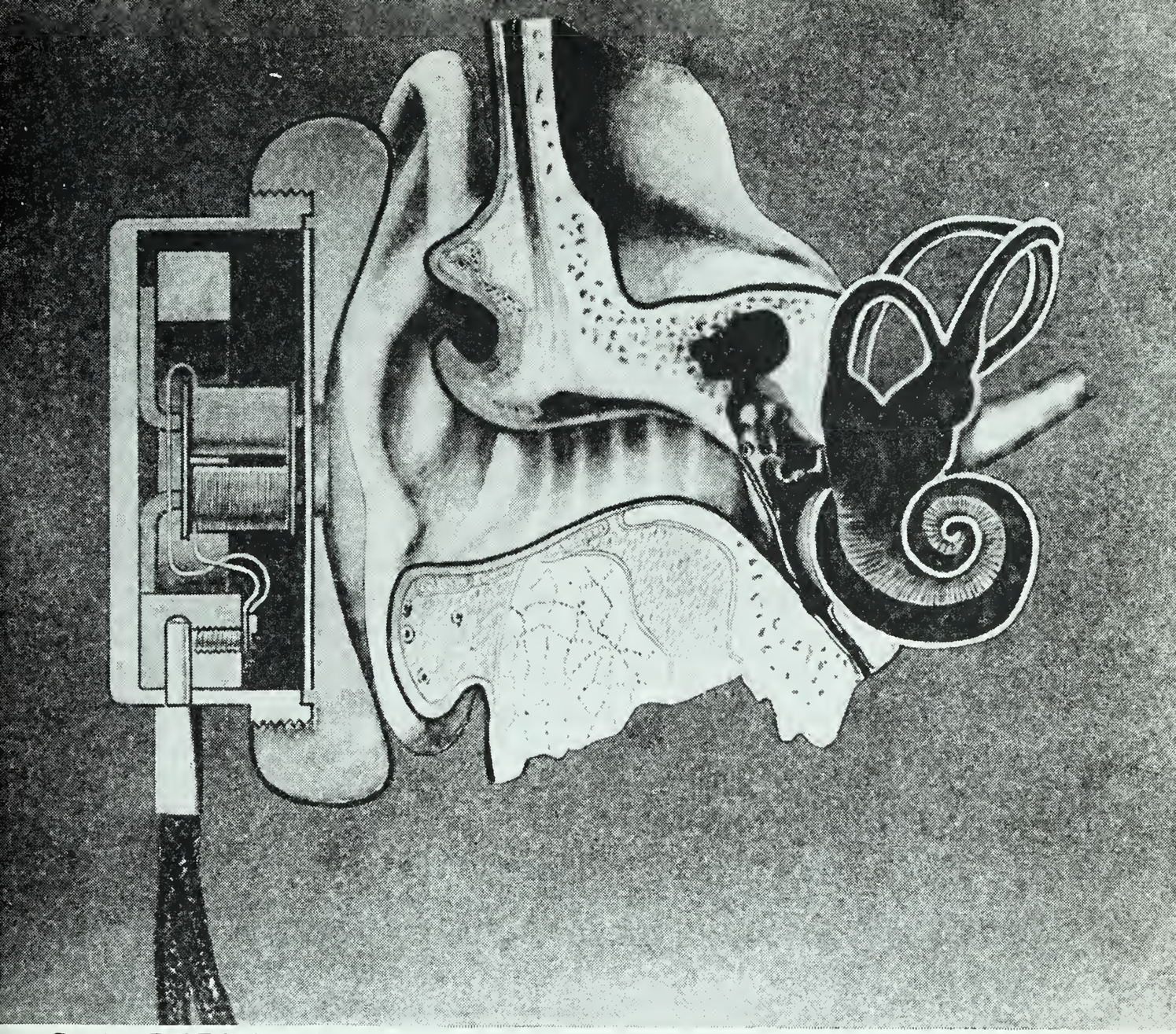
The transmission of energy by wave motion is very common. Imagine two small boats some distance apart on a quiet pond of water. If one boat is rocked violently, water waves are produced which soon set the second boat into rocking motion also. This would be a very good example of the transmission of energy by wave motion. We have already studied the wave transmission of light, heat, and other similar forms of radiant energy. Earthquake tremors are also transmitted through the solid earth by waves.

There are two kinds of wave motion: *transverse* and *longitudinal.* If a length of rubber tubing stretched horizontally between two supports is struck a sharp blow near one end, a wave travels to the other end and back again. Each point of the rubber tubing moves nearly vertically up and down at right angles to the direction of the wave; hence this type of wave is called transverse. In longitudinal waves, the particles move back and forth in the same direction as the wave itself. This type may be demonstrated by suspending a coiled spring from the ceiling and fastening the lower end securely to the floor. When several of the coils are pressed closely together and then suddenly released, a series of compressions and extensions travels up and down the spring.



Water waves and apparently light waves are transverse waves. Earthquake waves are complex, consisting of both types of wave motion. Sound waves are longitudinal, the molecular particles moving to and fro in the same direction the wave is traveling.

Sound waves are transmitted by solids, liquids, and gases. If



Courtesy Bell Telephone Laboratories

The telephone receiver is an electric mouth which sends speech waves through the ear canal to the eardrum. Three tiny bones transmit the vibrations to the fluid in the "snail shell," or cochlea, where strands of membrane in the coil pass the message along to the auditory nerves, which convey it to the brain.

someone taps with a hammer on a steam pipe in the basement, the sound may be clearly heard in a room several floors above. Nearly everyone has at some time tried to detect the approach of a distant train by placing his ear to the rail. According to legend, the American Indian was very good at discovering the approach of white men by placing his ear to the ground and listening for their footsteps. All of these examples relate to the transmission of sound by solids. If a tuning fork is set into vibration and the stem of it is touched to a tooth, the sound can be more plainly heard. The vibrations travel through the connected bones of the head. A modern device to aid the hard-of-hearing operates on this principle. A microphone

picks up sound waves in the air and transmits them electrically to a small vibrator which makes close contact with the head bones just behind the ear.

When swimming, have you ever held your head beneath the water while someone knocked two stones together under the water? If so, you know that sound is transmitted very well by a liquid. During wartime, surface vessels are equipped with special listening devices to detect submarines by picking up the vibrations which they set up in the water. Although liquids and most solids transmit sound much faster and with greater intensity than gases, air is the medium which ordinarily conveys sound vibrations to our ears.

The velocity of sound is very small when compared to the speed of light. Light travels at about 186,000 miles a second, but the speed of sound in air is ordinarily only about 1,100 feet a second. This great difference is the cause of our seeing the steam before we hear the whistle of a distant ship or locomotive. Likewise, the interval between seeing a flash of lightning and hearing the crash of thunder is due to this variation in the speed with which sound and light travel. At a track meet you probably have from a distance seen the flash of the starter's gun a few moments before hearing the sound of the report. Sound travels about 1,090 feet per second when the temperature of the air is 0° centigrade. As the temperature rises, the velocity of sound in air increases; the rate of increase is about 2 feet per second for each centigrade-degree rise in temperature.

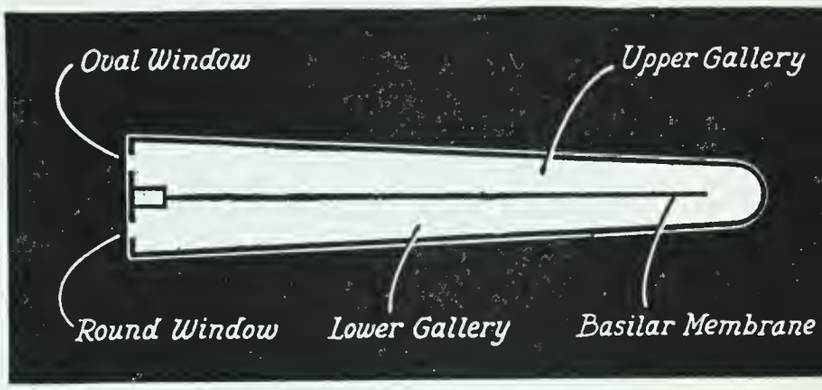
If we know the velocity of sound and the frequency of vibration, we can easily calculate the length of the sound wave by the use of the formula:

$$\text{wave length} = \frac{\text{velocity}}{\text{frequency}}$$

In standard abbreviations, the formula becomes $l = \frac{v}{n}$, from which we see that $n = \frac{v}{l}$, and $v = ln$. Wave length is considered to be the distance from one compression to the next or from one rarefaction to the next, as shown on page 558. Frequency means the number of waves that pass a given point in one second, or the rate of vibration.

• FROM SOUND WAVES TO SOUND SENSATIONS

Any vibrating object produces sound in the physical sense, but the *hearing* of sound involves additional factors. It has been argued



The diagram represents the cochlea as it would look if straightened out.

that if a tremendous rock slide occurred on a remote mountain 500 miles from the nearest person, there would be no sound. There would, of course, be vibrations, which could be transmitted through the solid earth and the air; there would be physical sound, or sound waves. However, since no ear would be present to pick up these sound waves and convert them into sound sensations capable of being interpreted in the brain, there would be no physiological sound. This imaginary situation is comparable to having your radio turned off or not properly tuned when a station is broadcasting—the radio waves are being produced and transmitted but are not being received.

The ear is the structure which converts sound waves into sensations of sound. It is a wonderfully complex mechanism composed of three principal parts as shown in the illustration on page 559. The first chamber, called the outer ear, is the part we see plus a short tube closed at its inner end by an elastic membrane, called the eardrum. Beyond the eardrum is the middle ear, which consists of a lever system of three small bones—the hammer, the anvil, and the stirrup—attached at one end to the eardrum and at the other end to another membrane called the oval window. Passing through the oval window, we come to the inner ear, a hard, bony structure known as the cochlea—so called because of its resemblance to a snail's shell.

If the coiled tube of the cochlea were straightened out, it could be represented as shown in the diagram. It is about one and one-quarter inches long and averages about one-sixteenth of an inch in diameter. The tube is hollow and is divided lengthwise, except at the tip, into two nearly equal parts by the basilar membrane. Both the upper and the lower gallery are filled with a liquid. At the outer end of the lower gallery is another elastic diaphragm called the round window.

The most remarkable part of the inner ear seems to be the basilar membrane. Although only one and one-quarter inches long, an average of one-sixteenth of an inch wide, and about one eight-thousandth of an inch thick, the basilar membrane contains about twenty-four thousand separate fibers. These vary from about

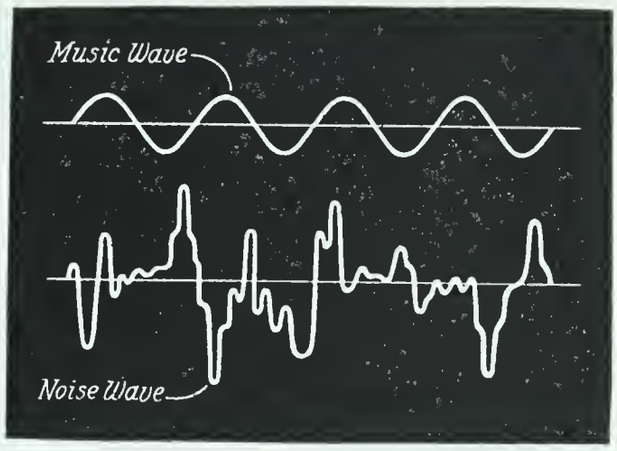
one-sixteenth to about one one-hundred-seventieth of an inch in length. Attached to these fibers are the endings of the auditory nerve—the usual pathway over which sound sensations pass to the brain.

The functioning of the ear is not entirely understood, but one theory of how we hear is widely accepted. The outer ear collects sound waves and directs them to the eardrum, which vibrates accordingly. By means of the hammer, anvil, and stirrup, this wave motion is passed on to the oval window and thence to the fluid in the cochlea. Waves of pressure variations pass through the fluid in the upper gallery and through the opening at the tip, then through the fluid in the lower gallery to the round window. Their excess energy is used up in causing this membrane to vibrate; thus, the waves are not reflected back again.

Each fiber in the basilar membrane seems to be definitely associated in some way with a particular frequency of sound wave. As sound waves travel through the fluid in the cochlea, it is thought that the basilar membrane is set into vibration and that various fibers respond to their own frequencies by vibrating strongly. Nerve impulses result which travel over separate nerves from each fiber to the brain and inform it of the various frequencies present even in very complex sound waves.

Words, music, and noise are made of waves. In the complex music of grand opera or a symphony orchestra, in the simple tone from a tuning fork, in the deafening noise from a boiler factory, and in speech—all that the ear receives is contained in the wave motion of the air. This consists of periodic pressure changes which are so small that the ability of the ear to detect them is truly remarkable. Of all pressure variations familiar to us, those in the atmosphere are probably best known. Our best mercury barometers usually measure such changes only to about one one-hundredth of an inch, which may indeed seem like a very small pressure change. But the least audible sound consists of pressure variations equivalent to only one two-billionth of the pressure of the whole atmosphere! This would be equivalent to the change in pressure produced by elevating a barometer only one thirty-thousandth of an inch. The weight of a snip of human hair only about one-thousandth of an inch in length would press as heavily upon the sensitive eardrum. These examples indicate how sensitive our ears really are.

The perception and the interpretation of sound sensations take place in the brain. Sounds are roughly divided into two groups—



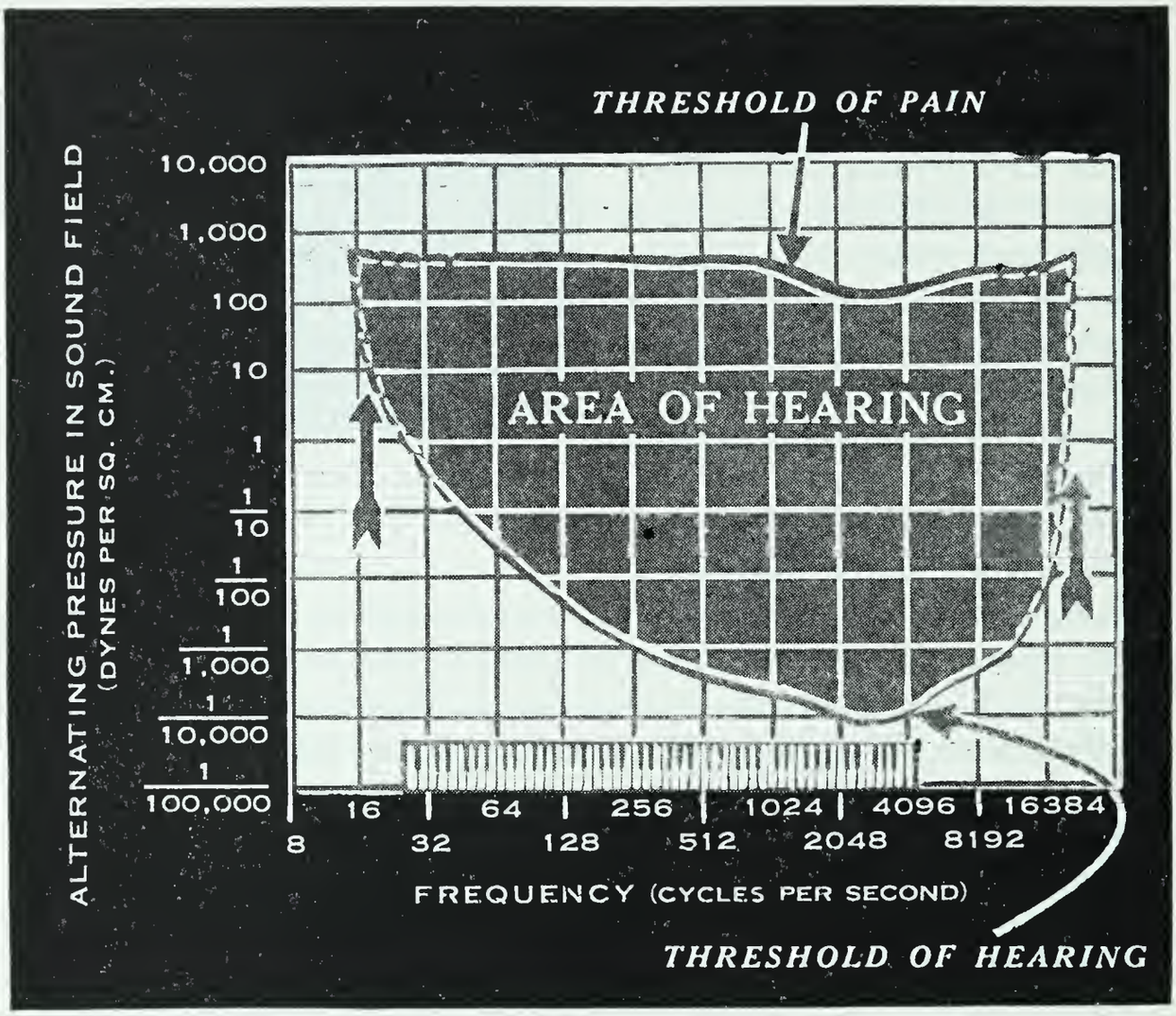
Comparison of wave forms of a simple tone and of noise.

namely, noises, which produce a disagreeable reaction on our part, and tones, which we receive with pleasure or indifference. The difference between noise and music is probably one of degree rather than of kind. Noise seems most likely to be composed of sounds of too short duration or of such complex structure that they cannot be analyzed or understood by the ear. Tones are sounds whose characteristics make them useful in producing music. The characteristics of tones are *pitch* (which depends on frequency), *loudness* (which depends largely on intensity), and *quality* or *tone color*. A simple tone, as from a tuning fork, forms an absolutely smooth, simple wave; music is more complex, but the ear is able to appreciate the relations among the component tones.

Still other factors may enter into the classification of sound as noise or music. Because of lack of training or fatigue, the ear may fail to appreciate the true character of sounds and thus classify them as noise. A notable example of change in classification from noise to music is Wagner's "Overture to Tannhäuser." Ten years after its first performance, it was still described by critics as "a commonplace display of noise and extravagance" and "shrill noise and broken crockery effects." Today, the Tannhäuser overture is classified with the world's greatest music.

The limits of our hearing ability have been analyzed and plotted on a scale. As shown by the diagram on page 564, there is an upper and a lower limit to the pitch of sounds which can be detected by the ear. The lower limit is around 12 to 16 vibrations a second, but the upper limit varies widely—perhaps from 12,000 to 20,000 vibrations a second—for different individuals. Above and below these frequency limits, we can hear nothing.

If we strike a tuning fork and let its vibrations die away, the sound gradually becomes fainter and finally inaudible—but the tuning fork is still vibrating, as can be shown in a number of ways. How? This indicates that sound, in order to be heard, must be at or above a certain minimum intensity level called "the threshold of hearing." The diagram shows that the smallest intensity of sound which we can hear varies with the frequency. The



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pitch to which our ears have the greatest sensitivity is located among the upper notes of the piano keyboard. The ear is less sensitive to notes of higher or lower pitch, and more sound energy is needed to produce a similar hearing sensation. At the extremes of the frequency limits of hearing, enormous amounts of sound energy are needed to make the notes audible, while beyond these limits, vibrations are not heard at all no matter how much energy falls upon our ears.

If a sound is made louder and louder, it becomes first disagreeable and then uncomfortable. If additional energy is supplied to the source of the sound, the vibrations set up in the various parts of the ear may be so violent as to cause pain or possibly injury to the ears. The maximum intensity level which our ears can tolerate without discomfort is called "the threshold of pain." As shown in the diagram above, the greatest intensity which the ears can comfortably endure also varies with the pitch, although the variation is much less than at the threshold of hearing.

Our ears, although extremely sensitive and at the same time very rugged, should receive habitual care and attention. Poor hearing may develop from a number of causes, but if discovered soon enough can often be corrected. Remove dirt and wax daily by the aid of a soft wash cloth or handkerchief over the end of the finger. Do not use small, pointed objects, like match sticks, hairpins, and pencils in cleaning the ears. The danger in such practices is emphasized in the old maxim, "Don't put anything into your ear smaller than your elbow." If wax is allowed to accumulate, it may harden and seriously interfere with good hearing. Hardened wax should be removed by a physician. Infections of the ear—usually in the middle ear and the tube leading from it to the throat cavity—may also lead to permanent deafness if not properly treated; have them attended by a physician. Remember that such infections frequently are caused by swimming in unclean water.

One of the best and most reliable tests of hearing consists of listening to the human voice in different pitch ranges from a distance of about 20 feet. Try this with both ears and compare the results. Since deafness comes on rather slowly, it is advisable to have fairly frequent tests or inspections of the ears. These are, of course, included in the thorough annual health examinations which many people take.

Exercises for Problem Study and Review

1. What is sound?
2. Compare sound and light as to (1) origin; (2) method of travel; (3) speed; (4) what finally becomes of each.
3. What is the formula for wave motion? Explain the meaning of the terms involved.
4. How do we hear? Be specific.
5. How do tones differ from noise?
6. What factors determine whether or not a vibration will be heard?
7. Do all vibrations falling upon the ear produce sound? Explain.
8. Explain the statement, "The ears are very efficient devices involved in a very inefficient process."
9. What precautions should be followed in caring for the ears?
10. Bacterial infections resulting from swimming in unclean water are usually caused by water which gets into the middle ear. How does the water reach the middle ear?

Problem 2: How do we produce sound?

Most of the sound which is useful is produced intentionally. We did not learn to talk by accident—the process was a slow and painstaking one. Likewise, musicians acquire their art as a result of a great deal of study and practice. True, we are subjected to other very different sounds which no one ever set out to create. Many of them came, for example, as a more or less necessary and unwanted by-product of our machine age. When unpleasant sound or noise becomes excessive we bend our efforts toward suppressing it. In this problem we shall investigate those sounds that serve man rather than those that annoy him. We are concerned here with the production of speech and music.

• FEELINGS PROVE MATHEMATICAL

Certain combinations of tones have marked effect upon our feelings or emotions. The siren disk is very useful in investigating these effects because it enables us to create complex sounds in which we know the exact frequencies that have been blended. When we force air through each of the four outer rows of holes in the revolving siren disk, one after the other, we hear a series of four musical tones—each differing in pitch from the others. If we force air through the first and fourth rows at the same time, the combination of the two sounds is very pleasing to the ear. Since the number of holes in the fourth row is 24 and the number in the outer row is 48, the frequency ratio of these two musical notes is 1:2. They are said to be an *octave* apart in pitch; in other words, *doubling the frequency of a note always raises the pitch one octave.*

When people sing together without attempting to sing in parts, the men automatically strike each note an octave below that sung by the women. This is the natural result of the difference in the pitch range of the male and female voices. Most people cannot rely upon their ears to give very exact information about the absolute pitch of a note, but they readily recognize when two notes are just one octave apart. Music has developed over a period of several thousands of years, simply on the basis of using those combinations of notes which pleased the ears. The remarkable feature of its development was revealed when scientists discovered that it had been built from notes whose frequencies are related to each other in

simple mathematical ratios. Typical of such ratios is the 1:2 ratio between octaves. *Man has unconsciously built his music upon a mathematical pattern!* Little wonder that Plato long ago insisted that harmony is innate in our souls. At any rate, the octave interval is fundamental in the music of all ages, all nations, and all races.

Other harmonious combinations of two notes are produced when the ratios of vibrations are 2:3, 3:4, 4:5, etc., but the effects are not so pleasing as for the simplest ratio, 1:2. Three notes sounded simultaneously produce the most pleasing combination when the frequencies are in the ratio 4:5:6. Any three notes with vibrations in this relation form a *major triad.* If to a major triad is added a fourth note which is one octave above the lowest note in the triad, a *major chord* is produced. The vibration rates of the notes in a major chord are therefore in the order of 4:5:6:8.

Since the siren disk has 24 holes in the fourth row, 30 in the third row, 36 in the second row, and 48 in the outer row, the simple frequency ratio of the four notes is 4:5:6:8, found by dividing by the smallest common denominator—which in this case is 6. Thus a major chord can be produced by forcing air through all four rows of holes at the same time, and a major triad by omitting the outer row. Tuning forks, organ pipes, and other instruments can also be used to demonstrate the triad and the chord by sounding the notes C-E-G and C-E-G-C′.

The musical scale has been built up from three major triads. The first note in any octave is termed the keynote, and the first triad used in building the scale starts with the keynote. Suppose we assign it a frequency of 24 vibrations per second. The necessary ratio (4:5:6) sets the frequencies of the other notes at 30 and 36 v.p.s. Do you see why? The highest note of the first triad is now taken as the lowest note of the second triad, hence its frequency is 36 v.p.s. The ratio now indicates that the other notes in this triad vibrate at 45 and 54 v.p.s. To get the upper note of the octave, we multiply the frequency of the keynote by 2 (24×2) and get 48 v.p.s. This is also the highest note of the third triad. Working the 4:5:6 ratio backwards, we find that the other two notes of this triad vibrate at 40 and 32 v.p.s. Since the note of 54 v.p.s. is above the upper limit of the octave, it must have a corresponding note one octave lower with a frequency of 27 v.p.s.

We now have all the notes necessary for the so called *major diatonic scale.* This scale may be summarized as in the following

table, which also gives the letters and syllables assigned to the various notes.

Frequency of vibration		24	27	30	32	36	40	45	48	54
Triad		1		1	3	1 & 2	3	2	3	2
Note	Letter	C	D	E	F	G	A	B	C'	D'
	Syllable	do	re	mi	fa	sol	la	ti	do'	re'

The first note of the octave can be assigned any frequency, but regardless of its value, the frequency of each of the other notes must bear the same ratio to it as indicated above. In the scale of the physical laboratory, middle C is set at 256 v.p.s. Hence the frequency of D becomes $256 \times \frac{27}{24}$, or 288; E is $256 \times \frac{30}{24}$, or 320; etc., giving the following vibration rates for the entire scale:

C	D	E	F	G	A	B	C′
256	288	320	341.3	384	426.7	480	512

Music is not always written in the key of C. It frequently happens that the range of a singer's voice is not suited to the key chosen by the composer of a song, and the pitch of the entire composition must be raised or lowered. This is possible because a key can be started with any note that is suitable. In other words, some note other than C may be selected as the keynote of the scale, and the composition can be transposed. For instance, if D is selected as the keynote, then the frequency of the next note would be $288 \times \frac{27}{24}$; the third note would be $288 \times \frac{30}{24}$; etc. The vibration rates of the notes in the key of C and the key of D are compared in the following table:

Note	C	D	E	F	G	A	B	C'	D'
Key of C	256	288	320	341.3	384	426.7	480	512	576
Key of D		288	324	360	384	432	480	540	576

Four notes in these two scales do not agree—E, F, A, and C′. The differences in E and A are so small the ear probably would not detect them, but in F and C′ the differences in frequency are

quite marked. Two new notes are needed if we wish to play in both the key of C and the key of D.

If all the possible keys are built and new notes are added wherever appreciable differences occur, a total of about seventy notes per octave is required. How would you like to take lessons on a piano having seventy keys to each octave? Handel, the great composer, had such a piano constructed, but no one could be found to play it well.

In studying the problem of a suitable scale that would include all the notes needed for all the keys, Johann Sebastian Bach observed that the seventy or more notes seemed to be grouped closely around the eight fundamental notes of the diatonic scale. He therefore proposed a compromise, an *even-tempered scale,* in which the octave is divided into twelve equal intervals. This scale is represented by the eight white keys and the five black keys in an octave on the piano. The new notes needed in addition to the eight fundamentals of the diatonic scale are represented by the black keys, each of which serves as the sharp of the note below it and the flat of the note above it. The even-tempered scale has proved so satisfactory that it seems most probable it will continue to be universally accepted. The notes and the corresponding frequencies of the even-tempered scale are shown in the table.

EVEN-TEMPERED SCALE

Note			v.p.s.
	C		256
C♯		D♭	271.2
	D		287.3
D♯		E♭	304.4
	E		322.5
	F		341.7
F♯		G♭	362
	G		383.6
G♯		A♭	406.4
	A		430.6
A♯		B♭	456.2
	B		483.3
	C		512

The next problem is to decide upon the standard of pitch. The standard middle-C tuning fork of the physics laboratory has a frequency of 256 v.p.s., and the entire octave is based on this keynote. This makes A have a frequency of 426.7 on the diatonic scale and 430.6 on the even-tempered scale. Musicians generally tune from A rather than C. Since about 1859, there has been wide use among musicians of the so-called *international pitch,* in which A has a frequency of 435. The standard of pitch adopted by the American Federation of Musicians is A = 440. Apparatus for producing this tone is kept at the Bureau of Standards in Washington, D. C., and the standard tone is constantly broadcast for reference use by musicians and musical organizations, notably symphony orchestras.



Courtesy C. G. Conn, Ltd.

Glancing from the top down, you see the violin, viola, violoncello, and string bass. What is the significance of their various sizes?

• SOUND PRODUCTION BY MUSICAL INSTRUMENTS

Nearly all music is produced by instruments in which strings, air columns, membranes, plates, or combinations of these are set into vibration. Since music is based on a definite scale of frequencies, instruments for making music must be designed so that we can use them to produce various vibration rates as desired. Science has formulated the laws of musical instruments.

Several factors affect the frequency of a vibrating string. In general, tightly stretched, short, thin strings give higher pitched notes than loose, long, thick ones. It is well known that when a string on a violin is made shorter by pressing the finger down on

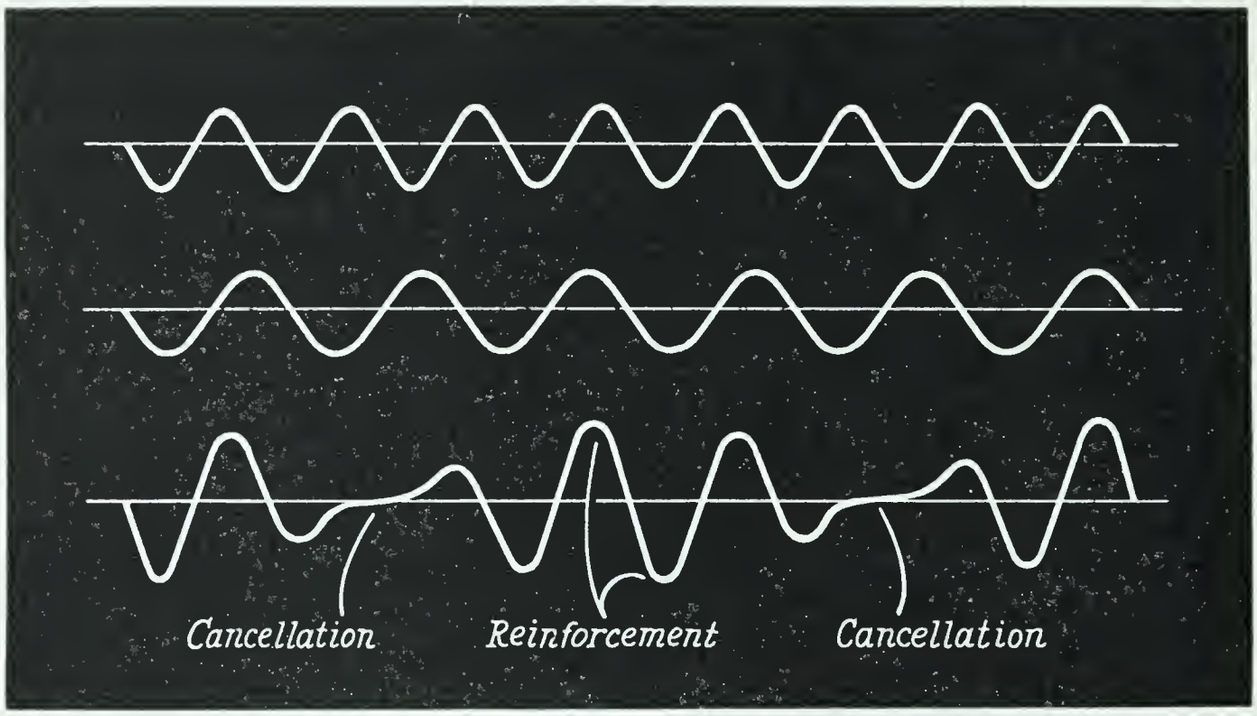
it, the pitch of the note produced by bowing the string is made higher. If the string is made one-half as long, the note is an octave higher; in other words, the frequency is doubled. Hence it follows that the frequency of a string varies inversely as the length. When the string is shortened to one-third its original length, the frequency is tripled; when reduced to one-fourth, the vibration rate is multiplied by four, etc.

When the violinist tunes his instrument, he tightens the string to raise its pitch and loosens it to lower the pitch. Thus we see that the frequency of a vibrating string is governed by the tension upon it. However, to make the frequency twice as great, four times the tension is needed—not two times. To make a given string vibrate three times as fast, the tension upon it must be multiplied by nine.

Examine the strings on a violin, piano, or other stringed instrument, and you will see that those for producing the bass notes are thicker and heavier than the others. The heavier a string is, the more slowly it vibrates.

Strings may vibrate as a whole and in parts. When a stretched string is plucked or bowed at its mid-point, it vibrates as a single loop and gives out the lowest note that it can produce. This note is called the *fundamental.* If a string is damped at its mid-point, as by placing the finger there, and is plucked at a point halfway between the mid-point and one end of the string, it gives off a note one octave higher. The string is now vibrating in two segments, and the pitch of the note shows that its frequency is twice as great. Other notes with vibration rates three, four, five, or more times the frequency of the fundamental can be produced by causing the string to vibrate in the proper numbers of segments, using the method described above. Such notes are called *overtones.* The following table shows the number of segments and the frequencies with which a string tuned to 256 v.p.s. must vibrate to produce various overtones.

OVERTONE			CORRESPONDING NOTE ON DIATONIC SCALE
Segments	Number of overtone	Frequency	
1	Fundamental	256	C
2	First	512	C'
3	Second	768	G'
4	Third	1024	C''
5	Fourth	1280	E''
6	Fifth	1536	G''
7	Sixth	1792	Between A'' and B''
8	Seventh	2048	C'''



Beats result when two sound waves of different frequencies alternately reinforce and cancel each other.

It is strange but true that a string can vibrate as a whole and in parts at the same time, and this ordinarily is what happens when stringed instruments are played. They give out their fundamental accompanied by several overtones. If the overtones correspond to some definite note in the scale, the effect is harmonious and the musical tone is richer in *quality,* or *timbre.* However, if the sixth overtone is produced, it does not correspond to any note in the scale and *discord* is the result—an unpleasant effect is experienced. To avoid the sixth overtone, piano keys are adjusted to strike the strings at a place which prevents them from vibrating in seven segments.

Another cause of discord is beats. When two sound waves of different frequencies are combined, they alternately reinforce and cancel each other periodically—just as we learned that light waves may interfere with each other to produce light and darkness. How this occurs for sound is pictured in the drawings. These periods of intensified sound followed by periods of greatly diminished sound or no sound at all are called *beats;* they can be demonstrated in a number of ways, as, for example, with tuning forks of different vibration periods. It has been proved experimentally that the number of beats heard a second is numerically equal to the difference in the frequencies of the two sound waves. When a tuning fork of 256 v.p.s. is sounded simultaneously with another one of 288 v.p.s., 32 beats occur each second. If the number of beats a



second is as small as 5 or 6, the sound is not particularly disagreeable; if the number is around 30, discord is at its worst; when the number rises above 60, the sound again becomes pleasant.

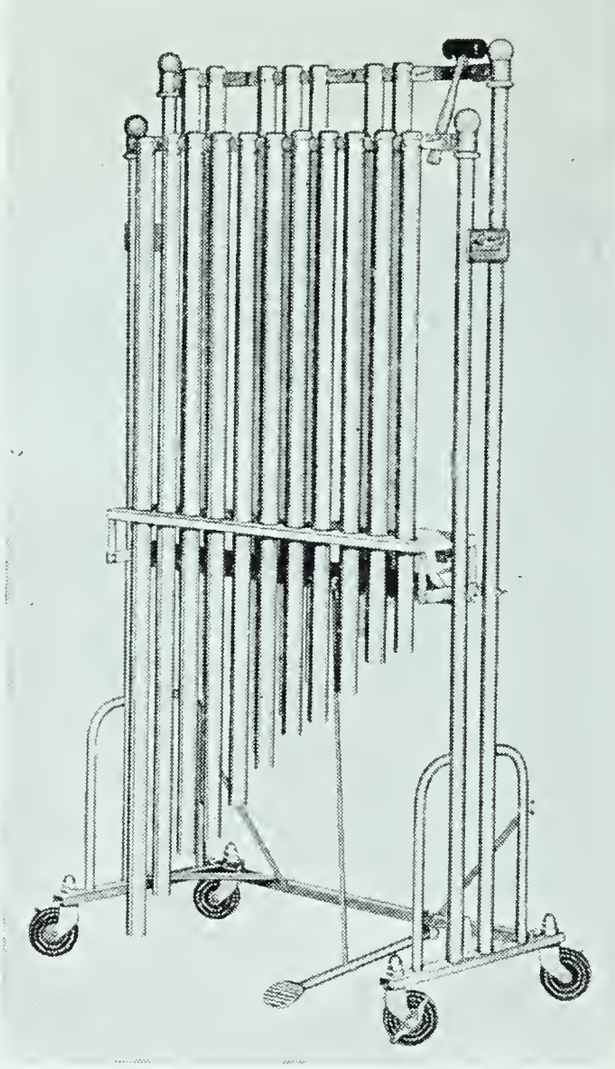
The loudness of musical sounds is controlled in two ways. Have you ever noticed that a particular rattle in your automobile occurs only when you are driving at a certain speed? That is an illustration of *sympathetic vibrations.* The part that rattles has its own natural frequency of vibration and is set into motion only when the vibrations of the engine reach the same value. Similarly, you probably have noticed that a metal picture frame may "sing" when a certain piano key is struck. In some cases, as in the marimba, sounds produced by one vibrating object are increased in intensity by the help of sound from air columns set into vibration sympathetically. Some singers have demonstrated that singing a high-pitched note with great vigor will set a thin glass into such violent sympathetic vibrations that it shatters.

Forced vibrations are more commonly employed to intensify sound. If several tuning forks are struck, one after the other, and their stems are held against a table top, a door, or a window pane a much louder sound is heard than when each fork vibrates alone. Thus we see that some objects can respond to a wide range of vibrations; that is, many different vibration rates can be imposed upon them. The sounding board of a piano acts the same way to intensify the sound of any vibrating string when forced to do so. Likewise, the thin wooden shell of a violin and the tightly stretched membrane of a banjo are forced to respond to the vibrations of the strings, thus giving much louder sounds than could be produced if the strings vibrated alone.

Pipe organs and other wind instruments produce sound by using vibrating air columns. Blow sharply across the open end of a test tube and you will readily see that air can be made to vibrate and produce audible sound. If you repeat this little experiment with another test tube of different length or with the same one after partly filling it with water, you will hear a sound of different pitch—lower if the second test tube is longer than the first and higher if it is shorter or if water was added to the original



n the bass clarinet and clarinet, the ound originates in the vibrating reed.



Chromatic chimes produce bell-like sounds when struck. Which of the solid bars gives off the lowest pitch?



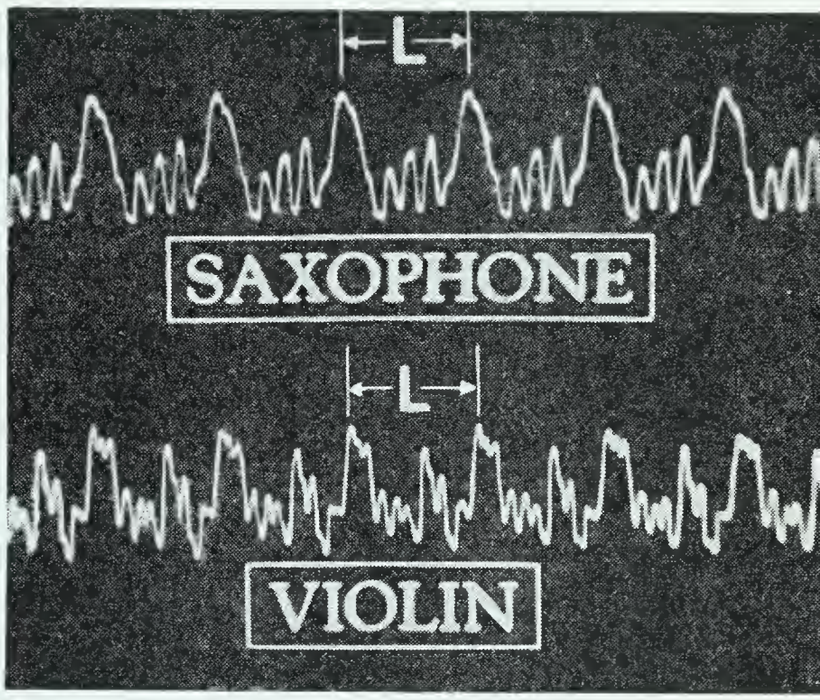
he two timpani, or kettle drums, differ in ze and range. Each timpano sounds a ngle pitch until it is re-tuned to another y adjusting the tension in the drumhead.

Photos courtesy C. G. Conn, Ltd.



In the French horn, the sound originates in the vibrating lips of the player.

test tube. Thus we see that, in general, the shorter the air column, the higher pitched is the note it produces when it is set into vibration. Application of this principle makes possible the production of the many notes by wind instruments. It is obvious how the length of the air column is altered as desired in the trombone. The saxophone, clarinet, flute, and similar instruments have holes in them which can be opened or closed by valves or the fingers, thus regulating the effective length of the air column. When one hole is opened, the pitch of the note produced is the same as if the column were only that long.

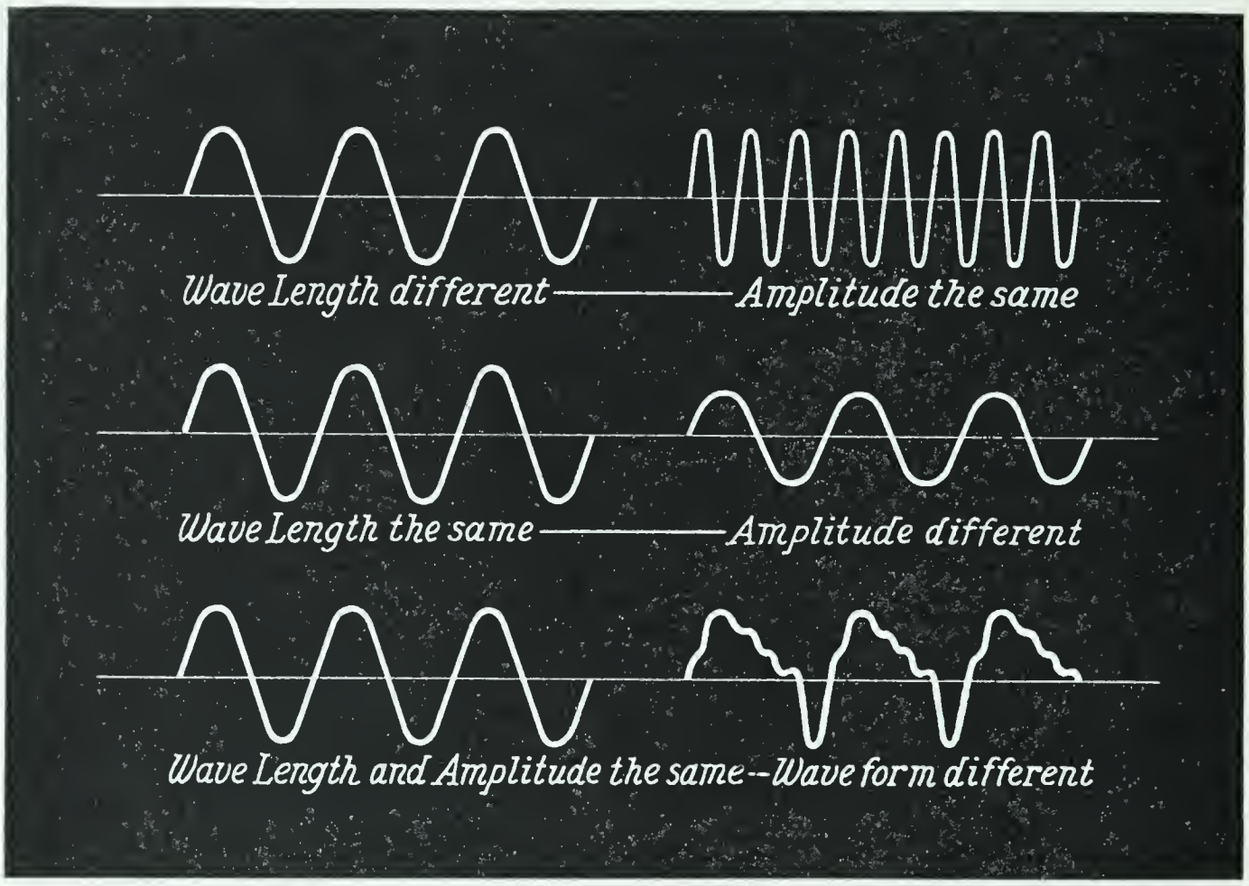


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These wave patterns are of the same note sounded on two different instruments. How do you account for the difference and the similiarity?

In the case of the pipe organ, the length of the pipe is fixed, and it is necessary to have as many different pipes as the number of notes on the keyboard. The pipes may be open or closed. It has been demonstrated that the wave length of the note produced by a closed organ pipe is four times the length of the pipe; for an open pipe, the wave length is twice the length of the pipe. How, then, would the notes from an open pipe and a closed pipe of the same length compare in pitch?

The air columns of wind instruments may be set into vibration in several different ways. Pipe organs are equipped with huge electric blowers which supply compressed air to the proper pipes when the keys on the console are pressed. The air jet is directed against the lip of the pipe in such a way that it vibrates back and forth and causes the air in the pipe to vibrate similarly. Likewise, a vibrating air jet is the source of sound in the flute, piccolo, and fife. In such instruments as the saxophone, clarinet, bassoon, oboe, accordion, harmonica, and reed organ, a vibrating reed sets the air column into vibration. Then there are the vibrating-lip instruments, such as the cornet, trumpet, and trombone. In most of these instruments, variations in pitch are regulated partly by the tension of the lips of the player and partly by valves which



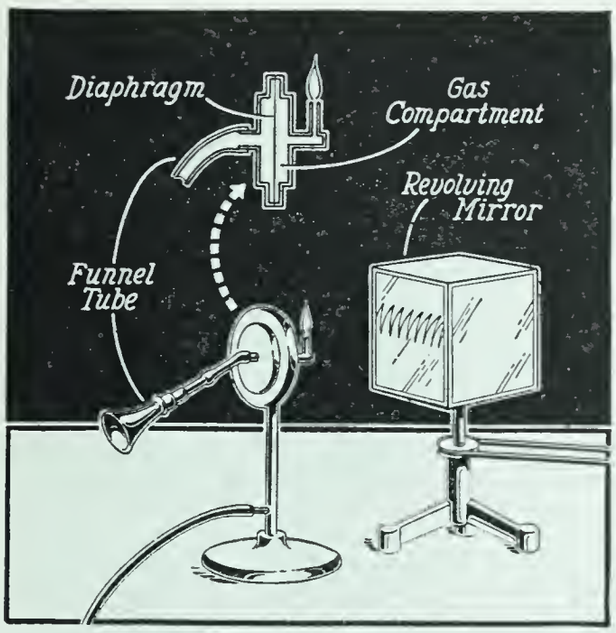
These diagrams illustrate the wave patterns of two sounds which differ in pitch (top), loudness (middle), and quality or timbre (bottom).

control openings that alter the length of the air column. The player partially determines pitch in the above lip-vibrating instruments simply by his control over air pressure. Extra pressure sometimes causes overtones to predominate over the fundamental.

The number and prominence of overtones that accompany the fundamental enable us to distinguish the various musical instruments. Few people would experience difficulty in correctly identifying each instrument if a certain note, such as A, were sounded successively on a violin, saxophone, and trombone. By various methods of sound analysis, such notes can be investigated and their wave forms determined. As shown in the diagrams, the sounds have the same wave length—and hence the same frequency and pitch—but differ in quality due to overtones. A tenor and a soprano singing the same note can be distinguished for the same reason. Study the above diagram of other differences between sounds.

The material used in the construction of some instruments affects their timbre; for example, metal organ pipes give higher overtones than wooden ones. It is possible to reproduce the quality of nearly all musical instruments on the modern pipe organ.

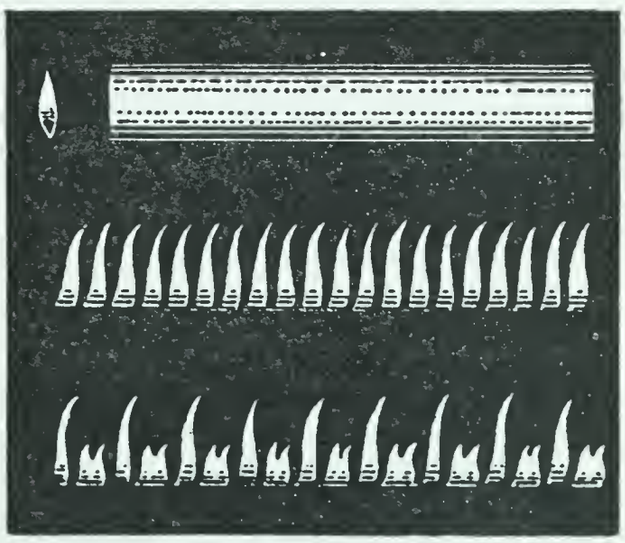
Sound waves may be analyzed or shown graphically by several



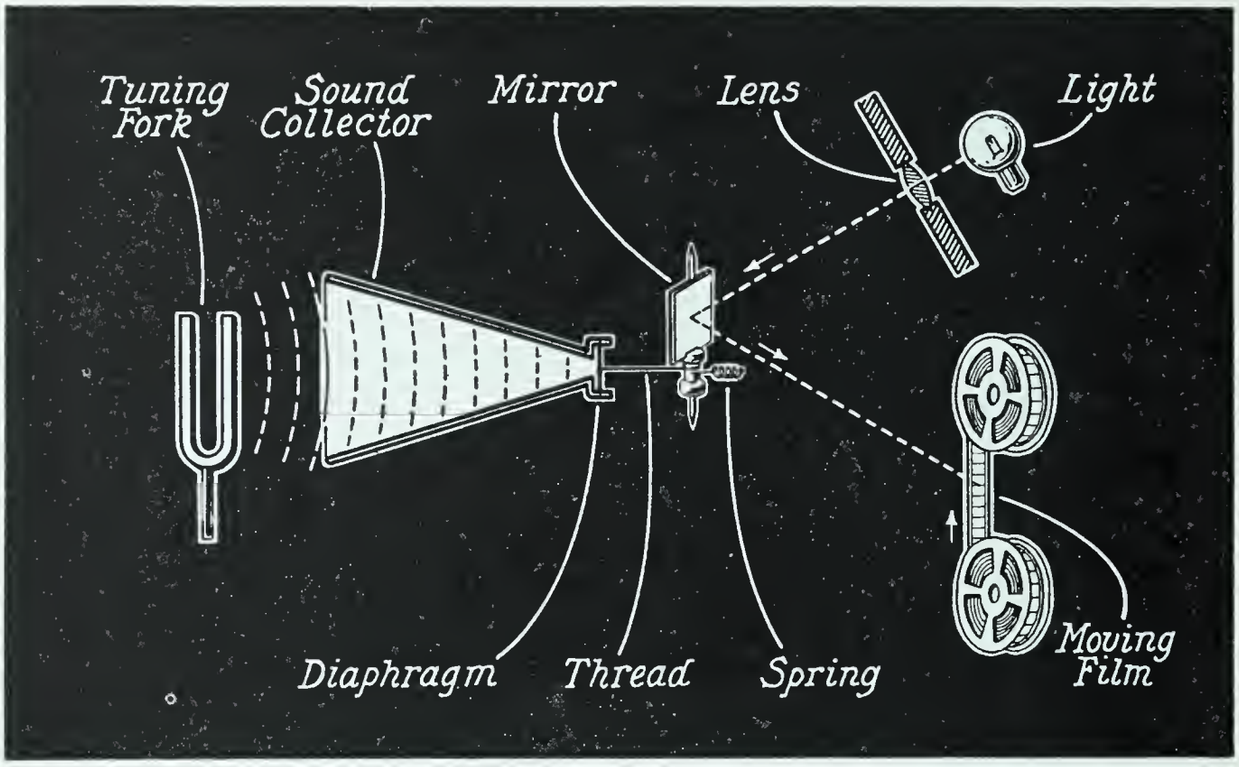
Shown here is a mamometric-flame apparatus for the study of sound waves.

methods. Since the ear does not analyze complex sounds into their components, it is clear that if we could break sounds apart or could "see" sound, the study of music, speech, and noise would be greatly facilitated. One of the first methods of tone analysis was devised by Hermann von Helmholtz, a German physicist; it operates on the principle of *resonance,* or sympathetic vibrations. Helmholtz prepared a set of hollow metal spheres of such size that each produced resonance with a tone of one definite frequency. When all of the resonators in a series are held to the ear, one after another, while a complex sound is being produced, it is possible to pick out all of the separate tones composing it. The resonators that are silent indicate that notes of their frequencies are absent from the sound being analyzed. By using the correct combinations of tuning forks, complex sounds have been accurately reproduced after analysis in this way.

The *manometric flame* enables us actually to see the form of sound waves. The essential parts of the apparatus are shown in the diagram above. When a sound wave enters the funnel tube, the diaphragm vibrates accordingly. This causes alternating compressions and rarefactions in the gas compartment, which in turn cause the flame to dance up and down with the same frequency and complexity as the original sound. The flame vibrations are too rapid to be seen directly, but they can be seen with the aid of the revolving mirror. When no sound enters the apparatus, a



Above are shown some images of a flame as seen in a rotating mirror.

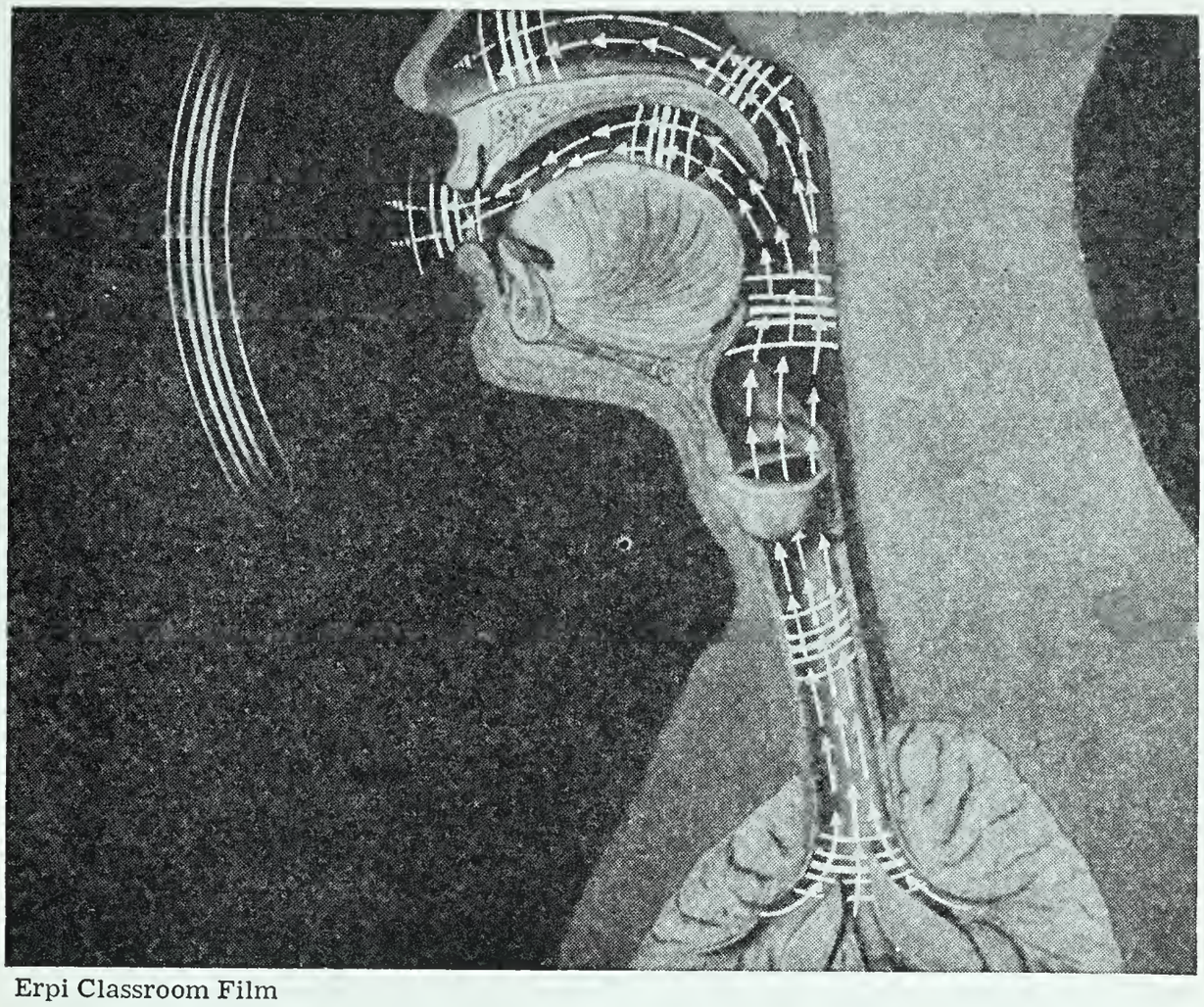


This drawing shows how photographic records of sound waves are made by means of the phonodeik.

continuous band of light is seen in the mirror. If a note of definite single pitch is viewed in the mirror, a series of jagged lines all of the same length is seen; if overtones are also present, the lines vary in length. Examples are shown in the illustration on page 577. High-frequency sounds beyond the range of human hearing may be studied by means of the manometric flame.

The *phonodeik* is an instrument by means of which sound waves may be photographed. It was invented by Professor Dayton C. Miller of the Case School of Applied Science. The drawing shows the principle of the phonodeik. Sound waves enter the horn and cause the thin glass diaphragm to vibrate. The tiny mirror twists on its axis as the diaphragm and the spring turn it first one way and then the other very rapidly. The small beam of light reflects from the mirror onto a strip of film moving at a right angle to the motion of the reflected light beam. As the beam dances from side to side, it traces a pattern of the sound waves on the film.

The *oscilloscope* is a more recent device for use in the study of sound. It also has many other applications. The details of the oscilloscope are complicated, but the principle involves shooting a stream of electrons between two sets of positive and negative plates and onto a chemically coated screen which fluoresces (glows) with a greenish light wherever bombarded by the electrons. One pair of positive and negative plates causes the electron stream to



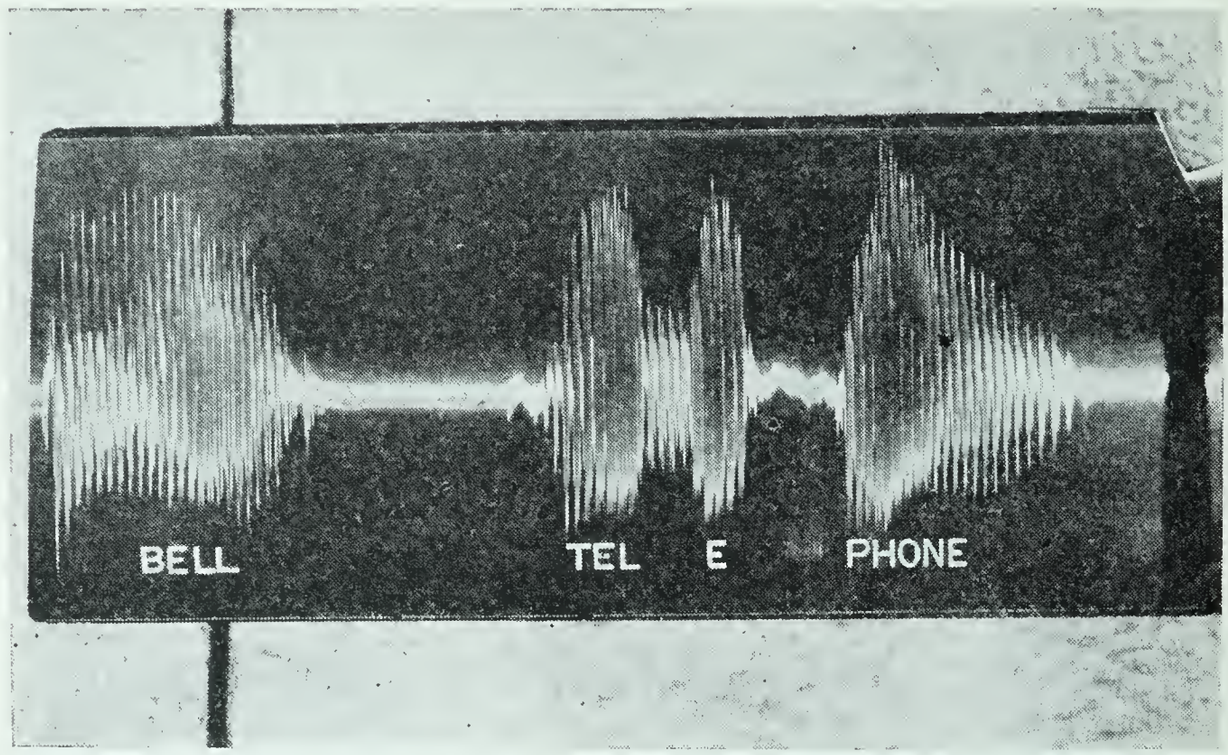
Erpi Classroom Film

As we force air up from the lungs through the glottis, the vocal cords vibrate. These vibrations result in the periodic pressure variations that give rise to speech waves.

move vertically up and down, while the other pair causes deflection from side to side in a horizontal plane. The amount of deflection either way depends on the strength of the electric fields, which in turn is controlled by the sound that enters the apparatus. When the two movements are combined, a correct pattern of the wave form is traced on the chemical screen. The oscilloscope is useful not only in the study of music and speech but also in the analysis of all types of noise, including those which may indicate defects in engines and machinerv.

• PRODUCTION OF SPEECH

Words, as well as music, are made of waves. In the production of speech, certain musical sounds (the vowels) and noises (the consonants) combine to form complex waves which human ears later receive and interpret. Vowels are primarily vocal-cord sounds, while the consonants are fundamentally breath sounds controlled



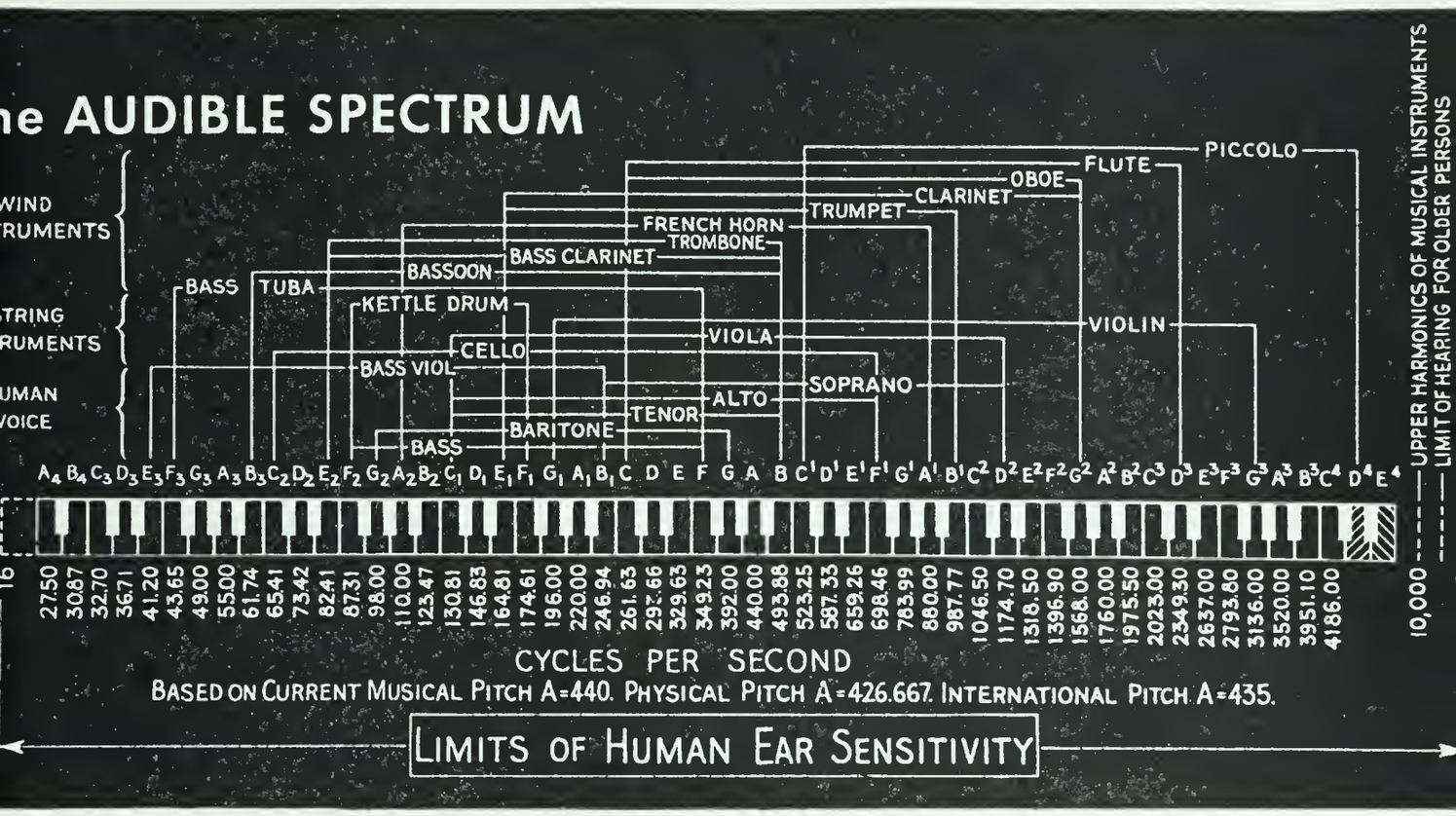
Courtesy Bell Telephone Laboratories

The photograph shows how the electric current is varied when the words "Bell Telephone" are spoken into a telephone transmitter. How do you think this photograph of sound was made?

by the tongue, teeth, and lips. The sounds of the voice are produced by the rush of air past the vocal cords in the larynx. Pitch is determined by the length, tension, and thickness of the vocal cords, which are controlled largely by muscular action. When we have laryngitis, these cords become thicker, and, like the bass strings on the violin or cello, they vibrate more slowly; hence the voice drops and becomes huskier. On the other hand, during excitement muscular tension increases and the pitch of the voice rises, sometimes to a shrill shriek. The photograph shows the wave patterns of some spoken syllables.

The mouth and adjacent cavities of the nose and throat constitute an adjustable amplifier for the sounds produced by the vocal cords. This amplifier operates on the principle of resonance. It can be tuned to a wide range of pitch by varying the position of the tongue, lips, jaw, and other parts. Because of these and other characteristics, the human voice has been described as the most versatile of musical instruments.

You are characterized in large measure by the quality of your voice. If you heard any of your close acquaintances speaking in total darkness, you would experience little difficulty in identifying them even though you would not be able to see them. It would be almost as easy if they simply sounded their vowels; but if they



Courtesy *Electronics*

This chart gives the frequency of the various instruments of the orchestra and compares them with the standard keyboard piano.

sounded the consonants, identification would be difficult if not impossible. What you say is conveyed by your consonants; who you are is conveyed by your vowels.

These facts are interesting, but they also give a clue to one method of enhancing your personality and increasing your chances of success—which is a much more important item. The business, social, and political advantages of a fine speaking voice cannot be estimated in dollars, but they are very great indeed. No matter what you have to say—no matter whether you are saying it to an individual, to an audience of several hundred, or over the radio—your chances of "winning friends and influencing people" are much greater if you have poise and control of your voice, if you enunciate clearly, if you speak slowly in low pitch and without nasal twang. By and large, radio announcers have the best voices of all the people we ordinarily have an opportunity to hear talk. Many hints for improving your own speaking voice can be gained by carefully listening to these individuals. Fortunately, control over the factors which determine the quality of the voice—that is, breath control and the position of tongue, cheeks, jaw, etc.—can be improved by training and practice.

Exercises for Problem Study and Review

1. In what way has music proved to be very exact mathematically, although no conscious effort was made to make it so?
2. How can you build up a major diatonic scale?
3. Why are compositions transposed? Explain the mathematics of the change.
4. Why is the even-tempered scale a practical necessity?
5. What are the laws of strings? Give an application of each law.
6. Explain and illustrate the use of forced vibrations and sympathetic vibrations in musical instruments.
7. What methods are used to analyze or to "see" sound? What use is made of them?
8. Interpret the statement, "What you say is conveyed by your consonants; who you are is conveyed by your vowels."

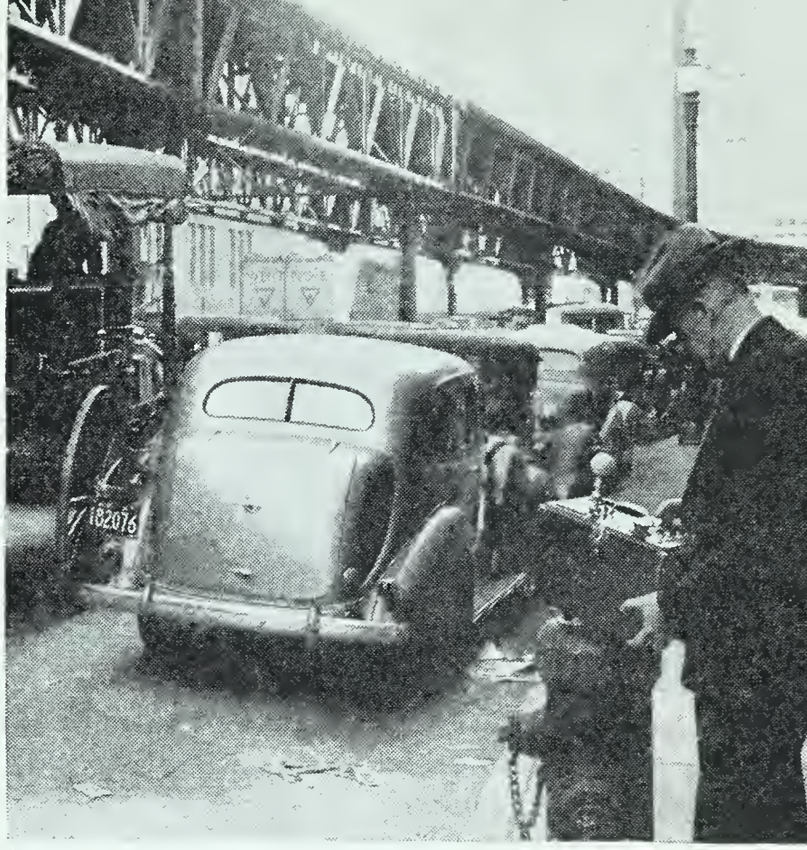
Problem 3: How do we control and use sound?

• SOUND OUT OF CONTROL

Noise has become a major problem in our civilization. We are becoming more and more concerned about what excessive noise does to us. Most of the sounds that wear on our nerves came with the machine age. Not so many years ago there were no such things as automobile horns, pneumatic riveting machines and drills, elevated trains, streetcars, subway trains, blaring radios, airplanes, and trucks. All contribute their share to the familiar din of the modern city, and many of them have encroached even into the rural areas. They may all be useful, but perhaps we should stop to consider what machines are doing to us while they are acting as our servants. We might also ask if so much noise is necessary; it certainly is not desirable.

Irregular sounds like the rattling of paper or the roar of street traffic to which no definite pitch can be assigned are usually classified as *noise*. A previously stated definition explained that noises are sounds which produce disagreeable or irritating effects on our ears. According to this latter viewpoint, it is possible for one person to classify as noise a sound which another person would call music.

The noise problem has been studied from three angles. They are: (1) its annoyance effect; (2) its effect on health; (3) its effect upon efficiency. The effect upon efficiency is the easiest of the three to measure. Experiments have been made which show that



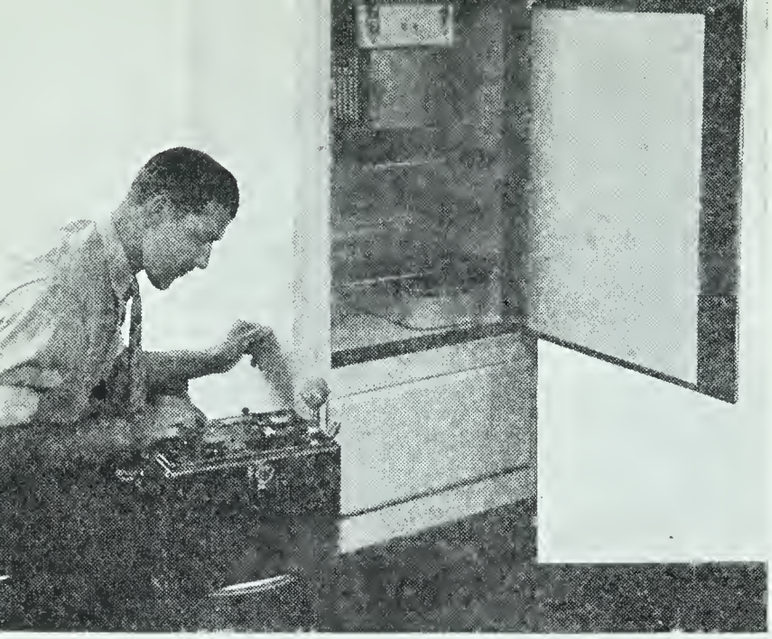
Courtesy General Radio Company

One step in solving the problem of city noises is to determine how much noise really exists. The observer is using a sound-level meter to gather this data.

typists, weavers, persons assembling temperature regulators, and workers in general produce more and make fewer mistakes when their surroundings are relatively quiet than when they are noisy. Sometimes, as in the case of the weavers, the decrease in efficiency due to noise has been slight—only 1 per cent; oftentimes it has been much greater. One of the striking results of the experiments has been to demonstrate the amazing ability of humans to adjust to changes in their environment. The experiments showed a great drop in efficiency when workers were first subjected to the loud noises. In a few days much of this lost efficiency was recovered. The adaptation was not complete, however, since day after day the decrease in the production of the workers was greatest when they were first subjected to the noisy surroundings. This seems to indicate that they had to become reaccustomed to the noise each day, although they did it much faster than at first.

The effects of noise upon the human body are very difficult to interpret. Complex loud noises are known to increase the rate at which one's heart beats and also the rate and depth of breathing. Again, the effect is greatest at first and decreases as the individual is subjected to these noises day after day. However, a change in the noise calls for a new adjustment. Very often it is impossible to interpret exactly the result of all this upon one's general health. In extreme cases of prolonged exposure to very loud noise, workers gradually become more and more deaf, and we can definitely say that this intense noise is harmful because it injures the ear. This has often happened to workers in boiler factories and steel foundries. The immediate effect of noise is to cause a mild and temporary increase in heart rate, in breathing rate, in pressure within the brain, and also a tightening of the muscles. However, it is not so easy to determine the permanent results.

Medical men lean to the opinion that the excessive noise of our



Courtesy General Radio Company

This picture shows the scientific way of answering the question, "How much noise?" Would your ears or the sound-level meter give the more reliable answer?

industrial age does have some harmful effect upon us, and many of them hold noise at least partly responsible for the great frequency of nervous ailments in our population.

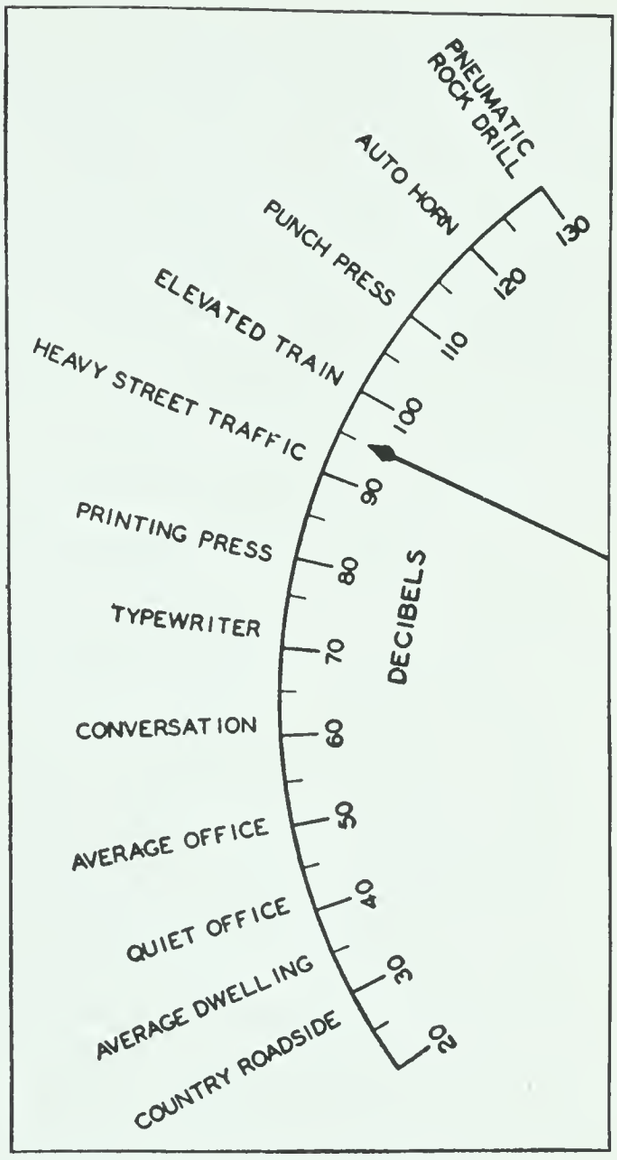
Private industry and governmental units are beginning to turn their attention toward the silencing of our machines. The task is an enormous one. Typewriter companies did much for the happiness and efficiency of office workers when they developed the "noiseless" typewriter. Manufacturers of refrigerators, automobiles, oil burners, clocks, and numerous other machines point with pride to the elimination of noise in their products.

New York City conducted a survey in 1929 and 1930 which offers a large-scale illustration of the fact that excessive noises annoy and irritate and that something can be done about them. Its Noise Abatement Commission published a questionnaire in the city's newspapers and received in reply more than eleven thousand complaints about various noises. Approximately half of the complaints were about noises which could be easily prevented. The result was an antinoise campaign directed against unnecessary and excessive blowing of automobile horns, shrieking automobile brakes, the use of loud speakers from trucks, etc. Some milk companies responded by using rubberized shoes on their horses and pneumatic tires on their wagons in order to help eliminate early-morning noises. The results of the campaign have done much to improve life in that city. Visitors to New York are impressed by the relative absence of certain kinds of noises common to many other large cities.

• KEEPING BELOW FIFTY DECIBELS

To be sure that noise has been reduced to a healthful level, we must define what that level is and have some way of knowing when our goal has been reached. Therefore, scientists have developed a "loudness" scale for sound. They called the unit the *decibel* in honor of Alexander Graham Bell. Average conversation has a

loudness of approximately 50 decibels. A continuous noise level above 50 decibels, whether it be in school, in the home, or in industry, is very undesirable. School classrooms are likely to have a decibel rating of about 50. School corridors during busy times may approach a decibel reading of 70. There are approximately 120 steps in the decibel scale between the zero point where sound is barely heard, and the point where it becomes painfully loud. Compare the intensities of the ordinary sounds included in the table. A sound of 60 decibels is ten times as loud as one of 50 decibels; one of 70 decibels is ten times as loud as one of 60 decibels, etc. Decibel readings are obtained with a sound-level meter. The ear certainly would not classify the relative intensities of different sounds so accurately.



Courtesy General Radio Company

This shows the wide range of sound levels met in familiar locations.

You will recall that the pitch of a sound depends upon its frequency. The intensity of a sound depends upon how much energy it possesses. Loudness of the sound differs from intensity in the sense that loudness is the actual sensation produced in the brain of the hearer. This also depends upon how well the ears and entire hearing mechanism function, as well as upon the intensity of the sound which strikes the diaphragms of the ears. Different people undoubtedly hear the same sound with a slight or even a considerable difference in loudness.

The noise level within a room is maintained chiefly by three methods. These are: (1) the back and forth reflection of sound waves that are already in the room; (2) the noise arising from sources located within the room; (3) the transmission of more noise from outside the room. If the walls and ceilings have hard sur-

faces, sound waves already in a room may bounce back and forth several times before their energy is all used up. Windows, walls, ceilings, and floors allow sound vibrations to pass through them into the room. Consequently, attempts to sound condition buildings have centered about controlling these two ways in which the mixture of sounds builds up to an excessive level.

Comparatively little can be done, except at great expense, to eliminate transmitted noise after the building is constructed. Double wall construction gives better insulation against sound than the usual single wall, and even more protection is obtained if there is a minimum of structural connection between the two walls. Ceilings can be suspended so that they are not in direct connection with the walls. Certain broadcasting studios are actually "floated" within the building to eliminate the entrance of unwanted noise. Without such structural foresight in apartment dwellings, there is not much to be done about the person who insists upon doing acrobatics in the room above you.

Nine-tenths of all outdoor noise that gets into our homes and other buildings enters through the windows. If this is excessive it may prove desirable to install double windows. These are sometimes nonmovable, and ventilation is then provided by a special ventilating system. The advantage of this method of eliminating noise for a building located on a noisy street is obvious.

When noise can neither be eliminated at its source nor be prevented from gaining entrance to our homes and buildings, the next best thing is to reduce it after it gets there. Curtains, draperies, hair felt, carpets, persons' clothing, and upholstery on furniture are examples of good sound absorbers. A heavy carpet may absorb as much as 15 per cent of the sound within a room. Gymnasiums, gamerooms, swimming pools, and similar more or less empty rooms with hard surfaces are often noisy rooms. They lack those things which absorb large quantities of reflected sound energy and are bounded by surfaces which are good reflectors of sound. Acoustic wall boards or "tiles" made from such materials as plant stalks, cork, and asbestos are manufactured commercially for use on ceilings and walls as sound absorbers. They are perforated and made very porous to increase their absorbing capacity. The quiet atmosphere of many restaurants, schools, factories, and hotels is due to liberal use of such material.

The various materials used in sound conditioning differ somewhat in their ability to absorb sound. One kind may absorb certain frequencies much better than it absorbs other frequencies.

For this reason it is often advisable to analyze the noise which is to be reduced in order to find out what the dominant frequencies to be eliminated are. The standard unit for comparing the sound-absorbing capacity of a given material is one square foot of open window. All of the sound falling on such a space passes on out into the open and is, in effect, completely absorbed. Forty square feet of brick wall are required to produce the same absorption of sound; therefore it is 0.025 as effective as an equal amount of open space. Hair felt one inch thick is 0.55 as good as an open window; comparative values of other materials are as follows: carpets, 0.2; wood, 0.06; cork floor tile, 0.03. In a theater, each member of the audience absorbs 4.7 times as much sound as one square foot of open window.

Wallace Sabine, during the first years of this century, strikingly demonstrated that it is possible to use absorbing materials to correct excessive reverberation. Reverberation is the name given to the multiple back-and-forth reflection of sound within a room. Sabine is the pioneer in the study of this reverberation problem. In fact most of our knowledge about acoustics of buildings has developed since his work about 1900. Sabine's work on reverberation resulted from a very practical situation. The acoustics in the lecture-room of a newly built museum at an eastern university had proved to be very bad and he was given the job of correcting the situation. In fact, the reverberation in the room was so bad that a word spoken with ordinary volume could be heard for five and one-half seconds afterward. Professor Sabine arranged to borrow the cushions used on the seats of a nearby theater. Fifteen hundred of these were spread around the lecture-room. The results were striking. The duration of audibility for a sound from an organ pipe dropped from 5.6 seconds when the room was empty to 1.1 seconds when the cushions were used. Thus the effectiveness of reverberation control by sound absorption was established beyond question.

At this point we might ask, "Would it be desirable to get rid of all of the back-and-forth reflection of sound within a room?" The answer is "No," for it has been demonstrated that a certain amount of reverberation is desirable. With too much of it, sounds tend to be harsh; but with too little of it, they become dull and lifeless. Experiments reveal that the length of time during which reverberation should continue after the original sound depends upon the size of the room and whether we are considering speech or music. In an auditorium good for public speaking, the reverbera-

tion time may be about one second. For producing best musical effects, however, we depend on sonority—that is, the continuance of sound—and the ideal reverberation time may be two seconds or even more. Thus it is entirely possible that a hall or auditorium well suited for speaking may be acoustically bad for music, at least to a certain extent.

Another serious acoustic defect resulting from the reflection of sound is the presence of echoes. If a reflected sound reaches the ear one-tenth of a second or more after the original sound is heard, it too may be heard as a separate, distinct sound. Since sound travels at a rate of approximately 1,100 feet a second, it travels about 110 feet in one-tenth of a second. Because the sound must travel from the source to the reflecting surface and back again, this means that the reflecting wall must be at least fifty-five feet away from the source before distinct echoes can be heard. An amusing situation occurred at a large state university in a building which was not completed according to the original plans of the architect. As a result, the interior was left very plain with large, smooth surfaces suitable for excellent sound reflection. On one occasion when the university band was playing in the auditorium, the leader of the band mistook the echo for the direct sound and began to beat time with it. To make matters worse, the xylophone player was scheduled to play a solo with the rest of the orchestra as accompaniment. In the confusion some of the players followed the leader and shifted to the time of the echo, and others near the soloist followed the time of the original sound. Fortunately, it was later possible to correct much of the acoustical difficulty by placing absorbing materials on the surfaces which caused most of the echoes.

"Whispering galleries" are outstanding illustrations of the fact that sound waves can be brought to a point or focus. If a properly shaped reflector is used, sound waves that have spread from a source can be reflected in such a way as to bring them together again somewhere else. The guides perform an interesting demonstration of sound-focusing for visitors at our Capitol at Washington. The part of the Capitol building known as the Hall of Statues has a dome-shaped roof which does the focusing. A guide assembles his party at the appropriate position and then retires to a distant point. Here he speaks in a whisper directed toward the floor. His words, which are plainly heard by the visitors, seem to come to them from under their feet. One of these points is in



Courtesy Jacobson and Company, Inc.

This restaurant has been equipped with acoustic tile installed on acoustical plaster to keep down the noise level.

what was formerly the Republican side of the hall and one in the Democratic side. The guide tells many interesting stories of how profound political secrets were unintentionally revealed to the opposing party here.

Similar effects can be heard in many other places. Another notable example is found in the Mormon Tabernacle at Salt Lake City, Utah. The sound of a pin dropped at a certain place in one end of this large room can be heard distinctly at the other end.

The field of architectural acoustics is a growing one as you might well suspect. Since the beginning of the present century, engineers have become increasingly aware of the fact that the acoustics of a building is something that must enter into the planning along with such items as strength of materials, appearance, and provision for adequate heat and lighting.

If all of the planning for sound conditioning is postponed until after the building has been built, the acoustics is not likely to prove entirely satisfactory. As has been pointed out previously, it is then too late to arrange for adequate elimination of transmitted noise except at considerable added expense. In spite of present knowledge, many of our newest buildings do not conform to the requirements for comfortable, distinct hearing.

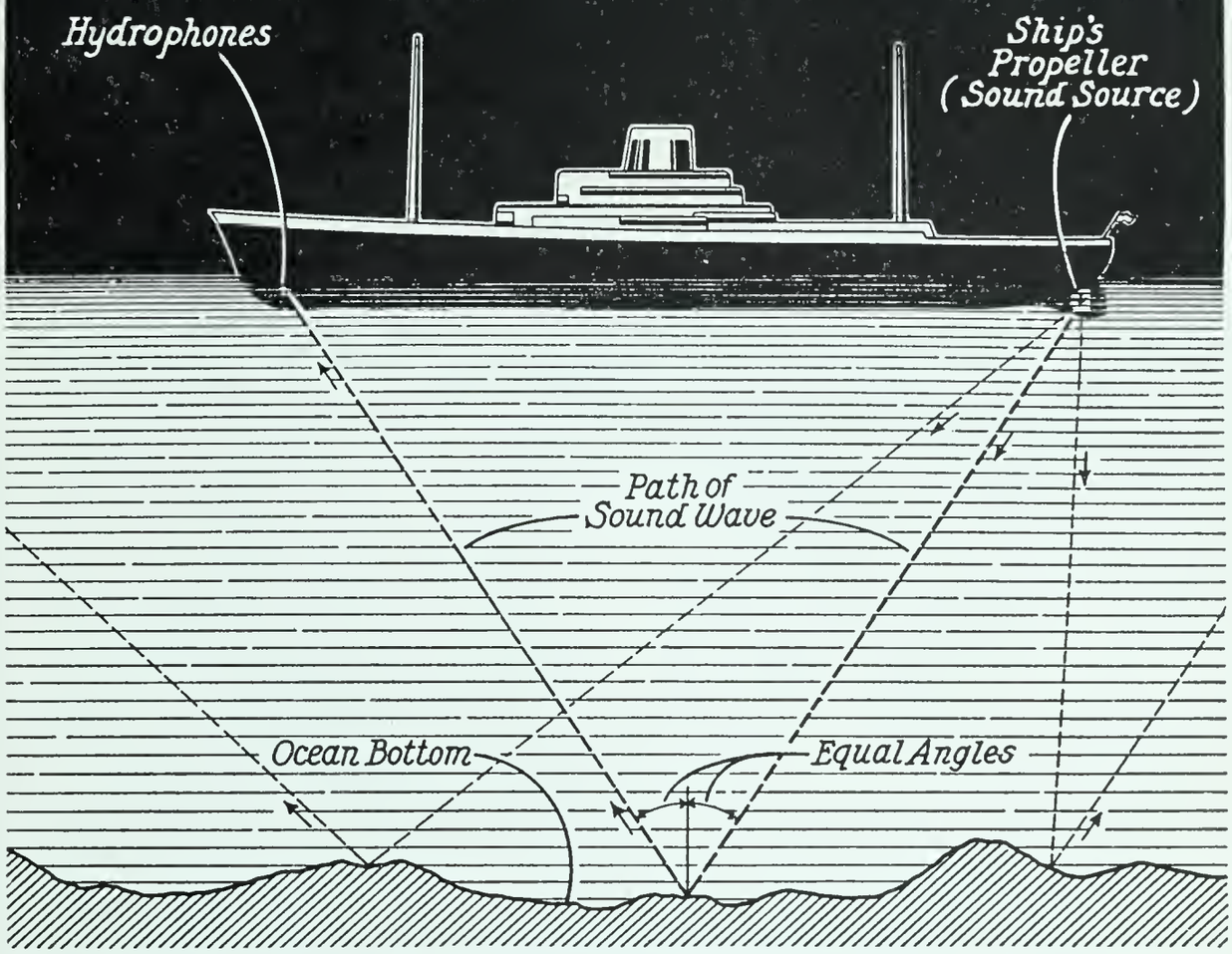
• PUTTING SOUND TO WORK

Useful sound plays an important part in the lives of ordinary individuals in this everyday world. We dodge an automobile when a horn is blown, answer the door when the buzzer sounds, turn our heads at a shout, pick up the receiver when the telephone rings, and cross the street when the policeman blows his whistle. In nations at war, people run to bombproof shelters when the air-raid warning sounds. The foghorn, fire siren, school bell, drum, and musical instruments all illustrate man's production and use of sound to control human emotions and behavior.

Everyone who has had any experience with automobiles or radios recognizes the value of sound in determining whether or not a mechanical device is in good working order. Likewise the physician uses sounds which originate in the vital organs of the body to find out much about human ailments. For example, healthy normal hearts do not sound the same to the trained ear as do diseased or defective ones. Listening to sounds in the chest region was one of the earliest ways by which the physician was able to get objective evidence concerning his patient's condition.

Before the invention of the stethoscope by René Laennic in 1816, the only way in which the doctor could listen to the heart beat or interpret the wheezing sounds coming from the chest of his patient was to place his ear directly over these organs. Today stethoscopes give a much fuller account of these sounds. Types of stethoscopes vary from the simple one carried about by the physician to elaborate electrical ones. The latter kind is able to amplify heart sounds so much that they can be heard by a whole roomful of people. This makes it possible for medical students to listen to a patient's heart beating while the instructor explains the meaning of these sounds.

The simple stethoscope used by physicians is a branching tube, at one extremity of which are two smooth ends which fit into the doctor's ears. The other end of the tube has a diaphragm which is placed directly against the patient's chest. Since the diaphragm of the stethoscope is much larger than the human eardrum, it collects more of the sound energy. It transmits the resulting waves to the listener's ears through the rubber tubing. Sound tends to spread out in all directions from a source unless prevented from doing so. As it spreads out, its intensity, and hence its effect upon the ear, becomes less and less. The walls of the tubes of the stethoscope help prevent this. We frequently use megaphones to prevent this spreading and also to give direction to sound.



Compare this method of depth-sounding with the method of parallax as shown in the diagram on page 246.

The oil prospector uses sound in locating places where oil is likely to be found. The method is possible because of the occurrence of peculiar structures, such as salt domes, above oil deposits. The prospector explodes dynamite and makes recordings of the resulting vibrations in the earth by means of seismographs. Since sound travels roughly about twice as fast in salt as in rock, the waves which travel down into the earth are refracted or bent by the salt layer in such a way that they return to the surface again. The salt layer also reflects some of the waves. From the recordings made by the seismographs of the returning vibrations, it is possible to learn of the presence of the salt domes. Their approximate depth can also be determined from the length of time required for the sound to reach the salt and return. The rate at which sound travels in various kinds of rock must be known, of course, or the calculations would not be possible. The value of this method of looking for oil is better realized when you consider that it may cost tens of thousands of dollars to drill a hole thousands of feet into the ground. At best there is a good deal of unproductive drilling, even if holes are bored only where the seismograph indicates that the ground structure is of the kind in which oil is often found.

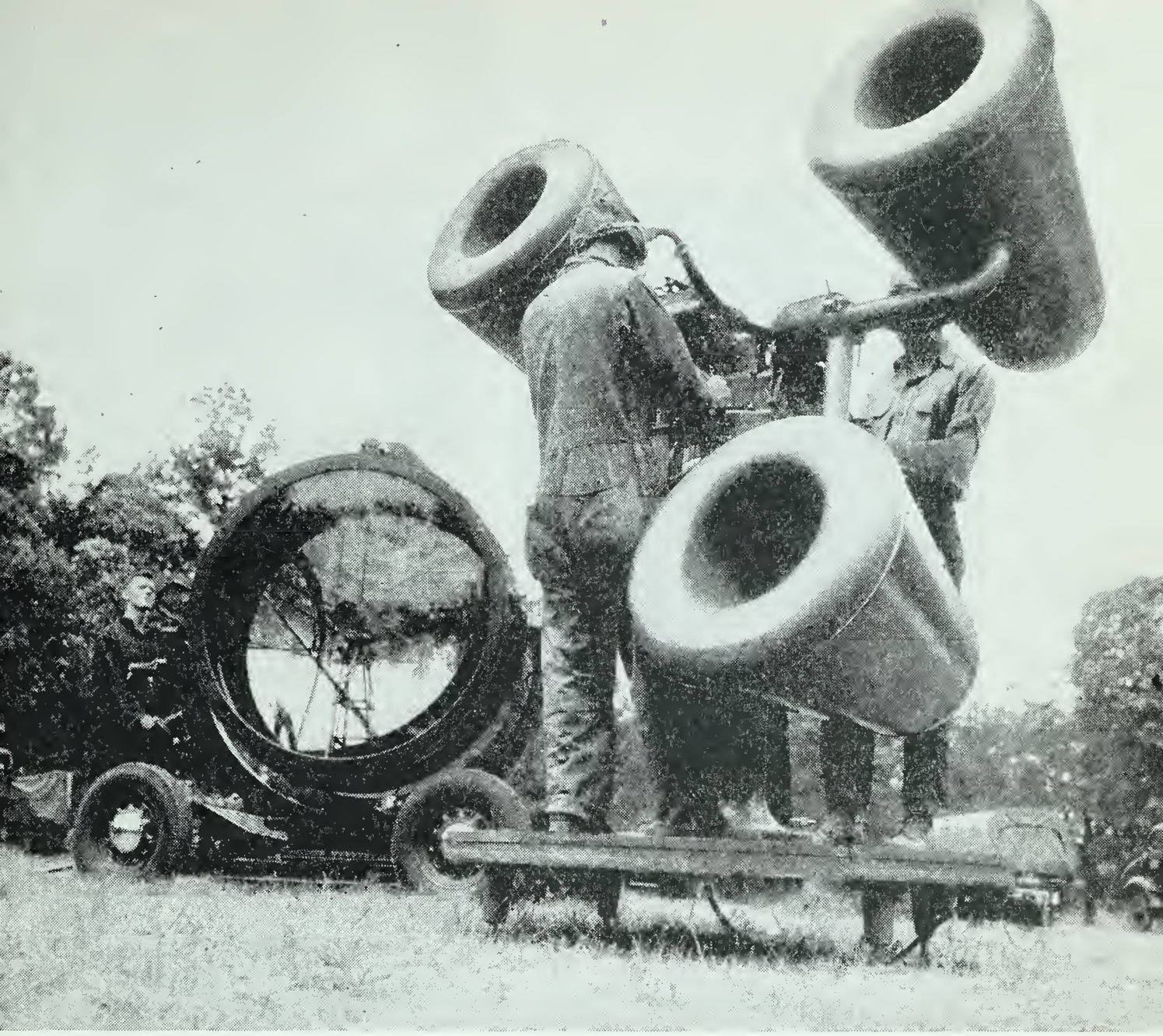
Echoes are also used to determine the depth of the ocean. In the modern study of oceans, it is no longer necessary to drop over-

board a piece of lead tied to the end of a line in order to find out the depth of the water. This old method was not very satisfactory in the deep parts of the ocean because of the difficulty of obtaining wire that would not break under the great strain. In addition, such methods are very time consuming. Today depth-readings can be obtained in less than a minute, even in water that is very deep.

A source of sound, such as the ship's propeller, is used as the original sound. Special microphones called *hydrophones* are used to pick up the echoes which return from the ocean floor. These hydrophones are located in the bow of the ship away from the source of the sound. With the hydrophones it is possible to determine the direction in which the sound wave returns from the ocean bottom. From this knowledge, the angle which the returning wave makes with a horizontal line at that point can be calculated. Since the original sound wave is reflected from the bottom at the same angle at which it strikes, it is possible to construct a triangle in which we know two of the angles and one side. The one side of the triangle is known because we can measure the distance between the hydrophones and the propeller or other sound source. The third angle is really known because we can get it simply by subtracting from 180 degrees. Why? We then have sufficient data to calculate the altitude of our triangle. The altitude of the triangle is, of course, the depth of the ocean at that point. The calculation, in fact the general method, is very similar to the method of parallax used by astronomers in finding the distance from the earth to other heavenly bodies.

Another method of ocean-sounding, as the obtaining of the depth is called, is simply to make a sound and record the time elapsing before the echo returns to the hydrophones. From the speed of sound in water, it is a simple calculation to determine how far the sound could have gone and returned within this time interval. This method is used in deep water where the method of determining the depth from the direction of the returning sound wave becomes less accurate.

The clue that two or more microphones would enable us to determine sound direction came from knowledge of the sound-receiving equipment with which nature has endowed us. It is the possession of two ears that enables us to determine more or less accurately sound direction. Sound waves which leave the sound source at the same instant will usually reach our eardrums at slightly different times because the distance that the sound must travel to one ear is likely to be slightly different from the distance

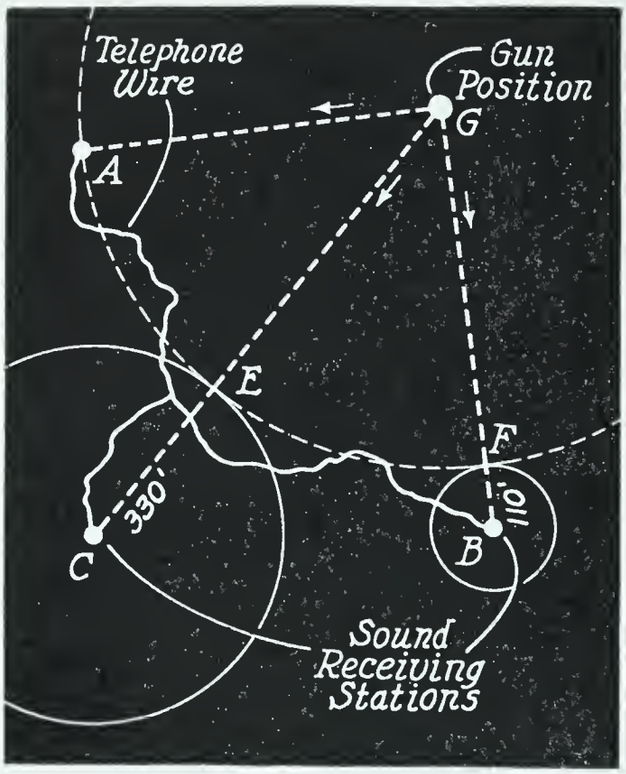


Courtesy Sperry Gyroscope Company, Inc.

The United States Army's sound locator and searchlight extend the human senses for the specific purpose of detecting and locating enemy planes. How do the three "ears" make it possible to locate the sound source precisely?

to the other ear. We have learned to use this slight delay in hearing to judge the direction of the sound source. When a sound reaches the two ears at exactly the same time, we are not so likely to be able to tell its direction accurately. In what relative position might the sound source be located when our sense of sound direction fails us?

In depth-sounding, then, it is possible to determine the direction from which an underwater sound approaches by using two hydrophones. If the hydrophones are joined by a rigid bar and rotated about the mid-point of the bar until an echo registers in both instruments at the same instant, the direction of the sound is known. The straight line from the point on the ocean bottom where the sound was reflected forms right angles with the middle



Sound-ranging spots an enemy field gun.

of the rigid bar joining the two hydrophones. The angle between this line and the horizontal can then be measured directly. This is the angle needed for the calculation. What possible uses can you think of for this device?

Supersensitive sound detectors are used to detect approaching airplanes during air raids. However, because of the relatively slow speed of sound, these "ears" indicate where the plane *was*—not where it *is*—unless adequate corrections are calculated. Infrared rays are sent out by the hot engine and exhaust of a plane, and these rays travel at a speed of 186,000 miles a second. Consequently, infrared-ray detectors have an inherent advantage, for they use a form of energy which travels many times faster than light.

Direction-finding by using a number of microphones is put to other uses, especially in war time. The navy uses them to locate enemy submarines and the army to locate enemy artillery. How sound-ranging spots an enemy field gun is shown in the illustration. A, B, and C are microphone locations. G is the gun being located. The sound of the gun is heard first at A, later at B, and still later at C. These times are recorded automatically by very accurate devices. From the time differences and a knowledge of the speed of sound in air, it is easy to calculate how much farther the sound had to travel to reach B or C than to reach A. Suppose the sound reaches B one-tenth of a second after it arrives at A and reaches C three-tenths of a second later than at A. If the velocity of sound in air is 1,100 feet a second, the sound traveled 110 feet farther in reaching B than in reaching A. Likewise, it traveled 330 feet more in going to C than in going to A. Circles are next drawn to scale on an accurate map of the region, using 110 feet and 330 feet as their radii and B and C as their centers. A larger circle is then drawn so that it passes through A and just touches the circumferences of the other two circles. The center of this larger circle represents the location of the enemy gun. By this method,

the most cleverly hidden weapon can be located accurately and destroyed by gunfire or airplane bombing.

Undoubtedly, the future will find man making more use of sound waves with frequencies so high that they do not affect our ears. When the number of vibrations drops below 16 a second, or rises beyond about 16,000 a second, the average human ear no longer hears them. Some animals have a greater range of hearing in this respect than we do. If you do not want to disturb your neighbors, you can, for example, call your dog with a Galton whistle set to give out a note of such high frequency that human ears will not hear it.

The range of frequencies that can be obtained using radio-vacuum tubes, certain crystals which vibrate very rapidly, and certain magnetic substances reaches as high as millions of cycles a second. Uses are being sought for such waves and already it is known that they have a deadly effect upon certain organisms, such as those found in stagnant water. Even tiny fishes and other very small animals die when subjected to them. These waves hold forth considerable promise as a convenient method of sterilizing food products, such as milk. We are just beginning to put these "ultrasonic" or "supersonic" waves to work.

Exercises for Problem Study and Review

1. Why is the noise problem more acute today than ever before? Is it a real problem? Support your answer with evidence.
2. Do your school, home, or community environments present any noise problems? How can they be reduced or eliminated?
3. Why is it so important to plan the acoustics before, not after, a building is constructed?
4. Can anything be done to improve the acoustics of existing buildings? Explain.
5. Did Sabine apply the scientific method in establishing the effectiveness of reverberation control? Explain.
6. Is reverberation ever desirable? Explain.
7. What is the difference between reverberation and echoes?
8. Under what conditions are echoes possible?
9. Explain how the physician, the automobile mechanic, and the oil prospector use sound to obtain objective evidence.
10. Do any special advantages result from having two ears rather than one? Explain.
11. How is ocean-sounding done? Direction-finding by sound?
12. List possible uses for ultrasonic waves.

Problem 4: How do we record and reproduce sound?

Again we come to an area where man's adjustment has been guided by the genius of the greatest of all inventors. It is hardly possible to form an adequate estimate of the influence which Thomas A. Edison has had upon this world of ours. For most people the mention of his name probably brings to mind the incandescent lamp, but those who are better informed also recall the motion picture, the phonograph, and others of his scores of inventions. Even the inventor himself could scarcely have realized the importance of what he was doing for the amusement and education of his fellow men when, in 1877, he patented his talking machine. Today recordings place the world's greatest music at our command—so much so that it may not occur to all of us that there are some persons alive who can recall the time when mechanical reproduction of speech and music was only a dream.

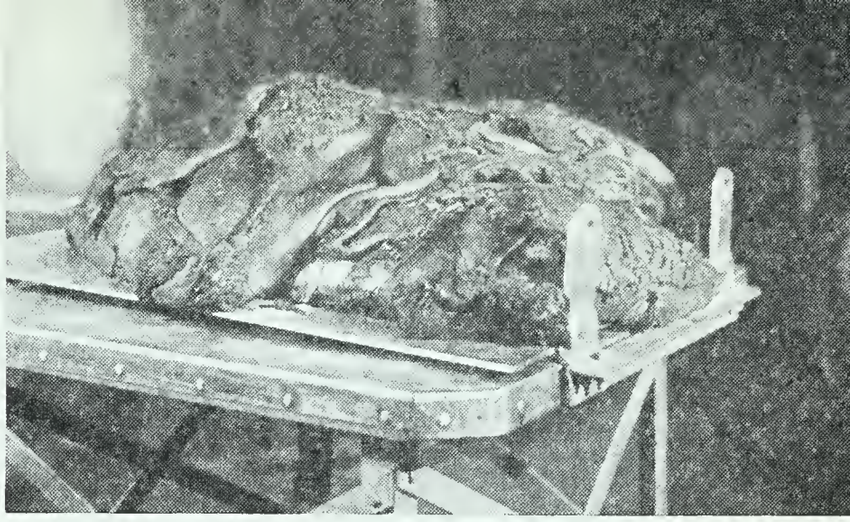
• MUSIC FROM PLASTICS

As implied in the problem title there were two parts to Edison's undertaking. They were: (1) that of making an actual record of the vibrations set up by the voice or instrument; (2) that of reproducing them at will from this recording. The modern dictaphone used in business offices is very similar in operation to the early forms of the phonograph. This instrument makes direct dictation to a stenographer unnecessary. The person using the dictaphone talks into the receiver from which the sound vibrations are transmitted to a diaphragm. You will recognize some similarity in parts between this much of the dictaphone and the stethoscope. Attached to the diaphragm is a needle, or stylus, which moves as the diaphragm vibrates when the voice waves strike it. As the needle moves, it cuts a path in the wax surface of a rotating cylinder. When the typist is ready to type the recorded message, the machine is adjusted so that the cylinder revolves with the stylus in contact with the groove which it previously cut into the wax. The process now becomes just the reverse of the original recording. When the jagged groove in the wax is dragged under the needle by the revolving cylinder, the needle again goes through the same series of vibrations as it did when it was originally cutting the groove. It is now the stylus which makes the diaphragm vibrate instead of vice versa. The vibrating diaphragm transfers

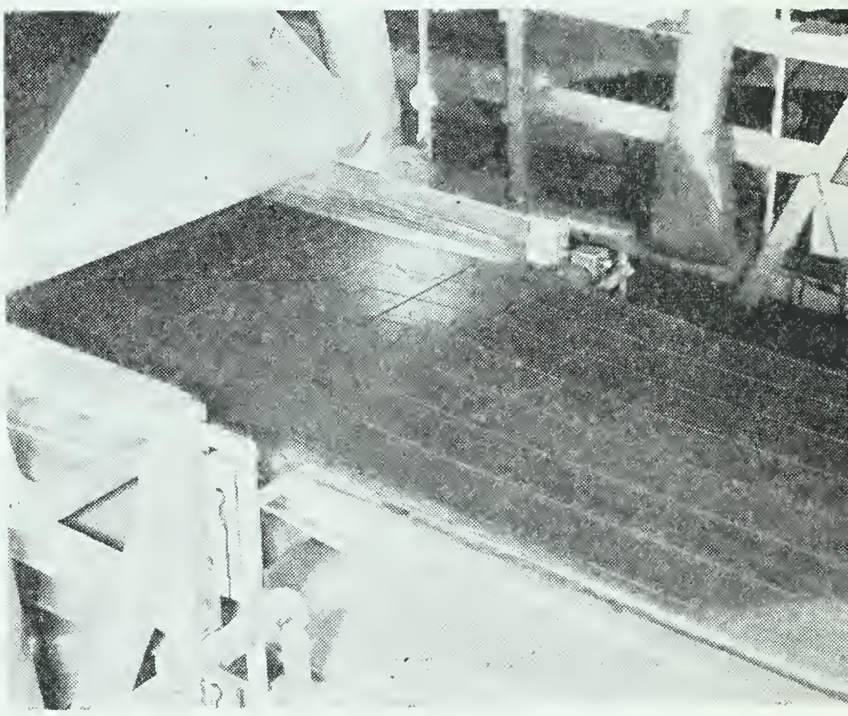
its energy to the surrounding air whose vibrations reproduce the original words when they reach our ears. A special tool is used to smooth the wax surface of the dictaphone record and prepare it for another recording.

Edison's early phonograph recorded and reproduced sound in much the same manner as the dictaphone. Indeed, the latter is simply a modification of the former. In the original phonograph the stylus made its tracing in a sheet of tin foil placed over a spiral groove on a metal cylinder. As the sound waves varied the pressure on the stylus, its sharp point crowded the tin foil in varying degree into the groove beneath it. In the reproduction of the sound, a stylus was again passed over these indentations and the vibrations were relayed to the diaphragm of the speaker. The use of wax instead of tin foil on the revolving cylinder was a later development. Still later, the cylinder was replaced by the revolving turntable which is standard on present-day phonographs. Modern records are made so that the needle moves sideways in the groove instead of up and down, as was formerly the case.

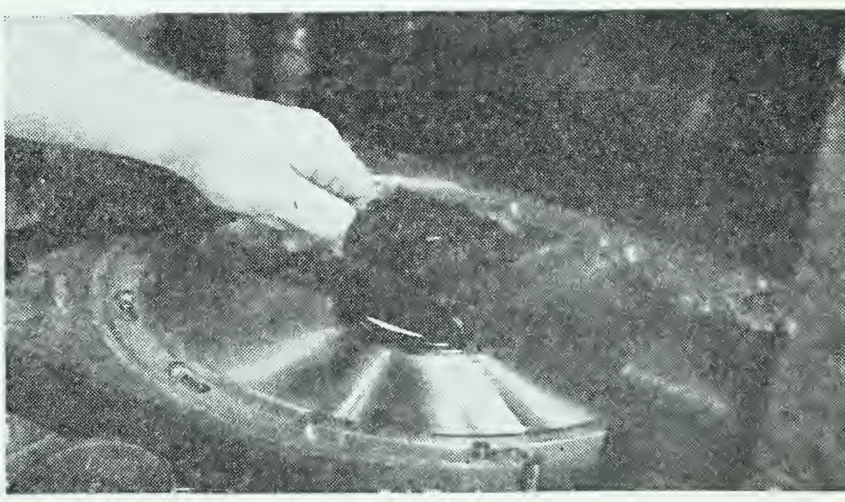
Today, the recording is cut with a sapphire into the surface of a soaplike compound,



1



2



3

Courtesy RCA Victor Manufacturing Company, Inc.

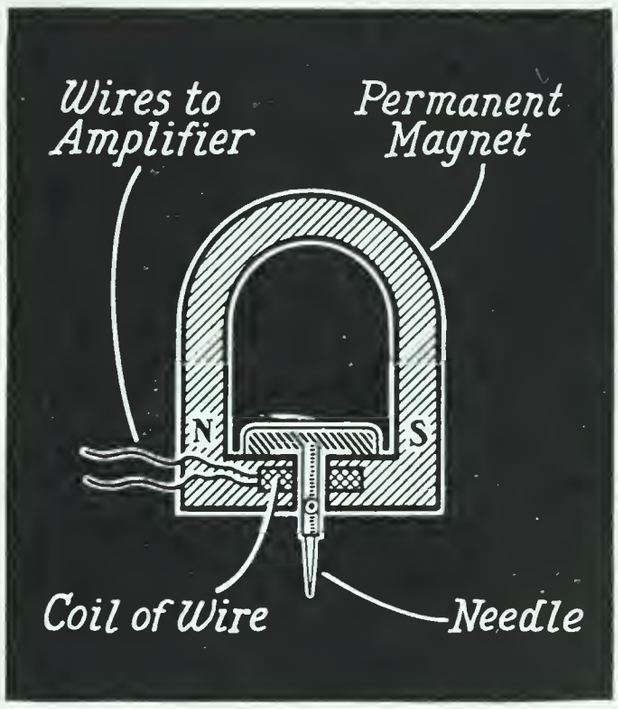
In making phonograph records, (1) plastic is made from resins (no wax or rubber) and (2) sheeted into "biscuits." These are (3) placed on the matrix for stamping—36 seconds later it may be your favorite record.

which is rotated at the same speed at which the finished record is to be played. At this point it would be possible to "play back" the disk, but the engraving would then be no good for further reproductions. Consequently, the next step is to make a negative for pressing out the "plastic plates" which we call records.

In the next step, the entire surface of the compound is coated with a film of finely divided silver or gold to make it an electrical conductor. It is then placed into a bath of copper sulfate and connected to the negative electrode for electroplating. With a bar of copper as the positive electrode of this electrolytic cell, the disk is plated with copper. After the copper deposit becomes thick enough, it is separated from the soaplike base. In this way an exact mold of the recording is obtained. Ridges on the copper disk correspond to the original grooves in the compound. This hard-copper electrotype or a model made from it by a similar plating process is placed in a hydraulic press and used for stamping the impression into the familiar flat disks. The plastic is heated prior to the stamping process, until it is soft enough to receive the impression. The same negative can be used many times for stamping out records.

• ELECTRICITY HELPS

The mechanical method of recording sound has now given way to a more elaborate electrical method. Electrical pickups have also largely replaced the mechanical method of reproducing music and speech from phonograph records. Edison's phonograph had certain disadvantages which have been at least partially overcome in modern machines. One big disadvantage resulted because the needle had to exert considerable force against the record. This gave rise to unpleasant scratching noise during reproduction, as well as causing ruinous wear on the record. The other chief disadvantage had to do with the quality of the reproduced sounds. The better brands of phonographs are now equipped with loudspeakers which can reproduce the original sound much more faithfully than could the mechanical sound boxes. Diaphragms such as the early ones used in phonographs and those now used in telephone receivers are capable of vibrating within a certain range only. To be a faithful reproducer of music and speech the diaphragm should have no set period of vibration of its own or else should have one which goes beyond the range of vibrations which affect the human ear. It should respond to high and low frequencies alike.

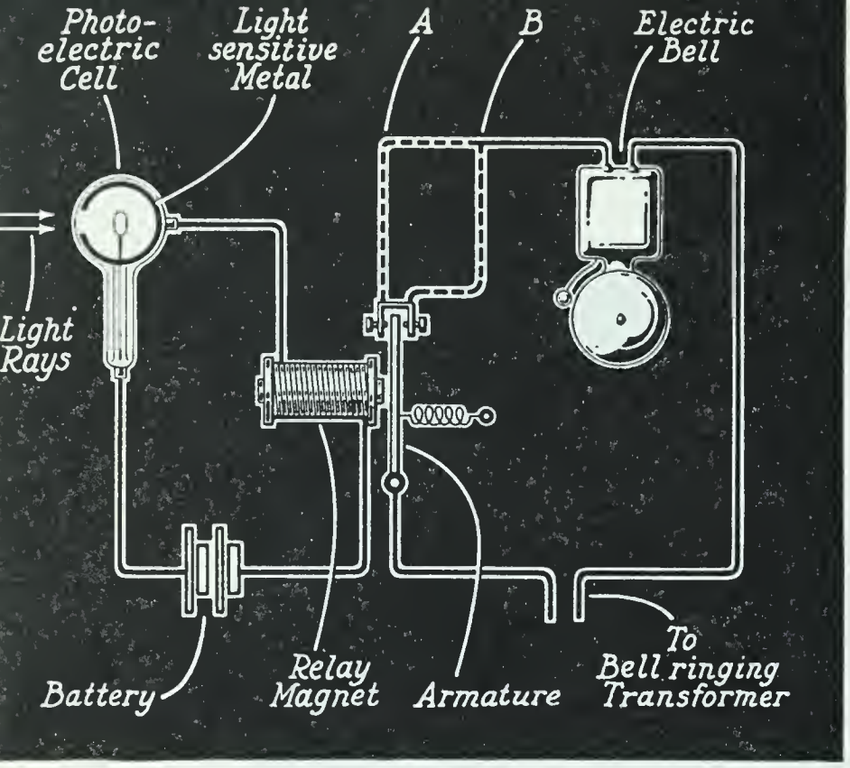


The electromagnetic pickup is really a small electric generator.

The electrical pickup is similar to the mechanical one, in that it uses the phonograph record to make a needle vibrate. However, the pressure of the stylus upon the record is much less, thus greatly reducing the attendant scratching and wear. The force exerted upon the needle need not be so great, because the needle is used simply to move a little armature located near an electromagnet instead of having to move a heavy diaphragm as in the early phonograph. The moving armature varies the magnetic field which surrounds it and thus induces a current in the windings on the magnet. Hence this device is really a miniature electrical generator. The current generated varies in strength according to the movements of the needle and is used to operate the loud-speaker. In combination radio-phonograph sets, the same amplifying system and the same loud-speaker serve each of the combined instruments. The radio and the phonograph both supply a fluctuating current to the speaker, and the speaker converts the electrical energy into sound.

The crystal pickup employs still less pressure upon the phonograph record. This device operates upon the principle that certain crystals generate minute electrical currents when the crystals are slightly twisted, compressed, or otherwise deformed. The motions of the needle in the groove of the record are passed on to a crystal, which in turn sends out electrical pulsations. These pass into the amplifying circuit and operate the loud-speaker as in any other method of electrically reproducing sound.

The moving-coil type of loud-speaker is widely used. In it the fluctuating current passes to a light coil made up of one or a few turns of heavy wire or tape. This coil has a paper cone, or diaphragm, attached to it and is suspended between the poles of a strong electromagnet. The magnetic field produced by the varying current in the coil reacts with the magnetic field within which the coil is suspended. The resulting forces of attraction and repul-



Light can be used either to stop or to start the ringing of the bell according to whether the circuit is completed as shown at A or at B. Can you modify this diagram to suggest other ways in which the photoelectric cell might be used?

sion cause the coil to vibrate in step with the pulsations of the current in the coil. Since the cone is firmly attached to the coil, it also vibrates, setting up sound waves in the air. A well-constructed loud-speaker of this type gives a nearly perfect reproduction of the speech or music that was originally recorded.

• FROM LIGHT TO SOUND

Recently a new principle has been introduced into sound reproduction—that of producing sound from a beam of light. As you probably suspect, it makes use of the "electric eye," or photoelectric cell. The action of this cell is based upon the *photoelectric effect*—that certain metals, notably sodium, cesium, potassium, rubidium, and selenium, give off electrons when light shines on their bright surfaces. Several types of photoelectric cells have been designed to make use of this effect. One kind consists of a vacuum tube coated on the inside with the sensitive metal and having a loop of wire at its center. When plugged into a circuit, the wire loop becomes the anode (positive), while the metal coating serves as the cathode (negative). When light strikes the cell, the metal gives off electrons, which are attracted to the anode. The number of electrons given off—and hence the intensity of the current in the circuit—varies directly with the intensity of the light falling on the sensitive surface.

Photoelectric cells are used in a variety of fascinating and important ways. The feeble current from the cell is used to open or close switches that control other circuits carrying heavier currents. These currents, in turn, operate electric motors, lights, and other appliances. Thus it is possible to open or close doors, turn drinking fountains on or off, operate burglar alarms, and do many other things which seem equally mysterious unless understood—simply by using a beam of light. Photoelectric cells are essential to the production of modern "talkies" and to television.

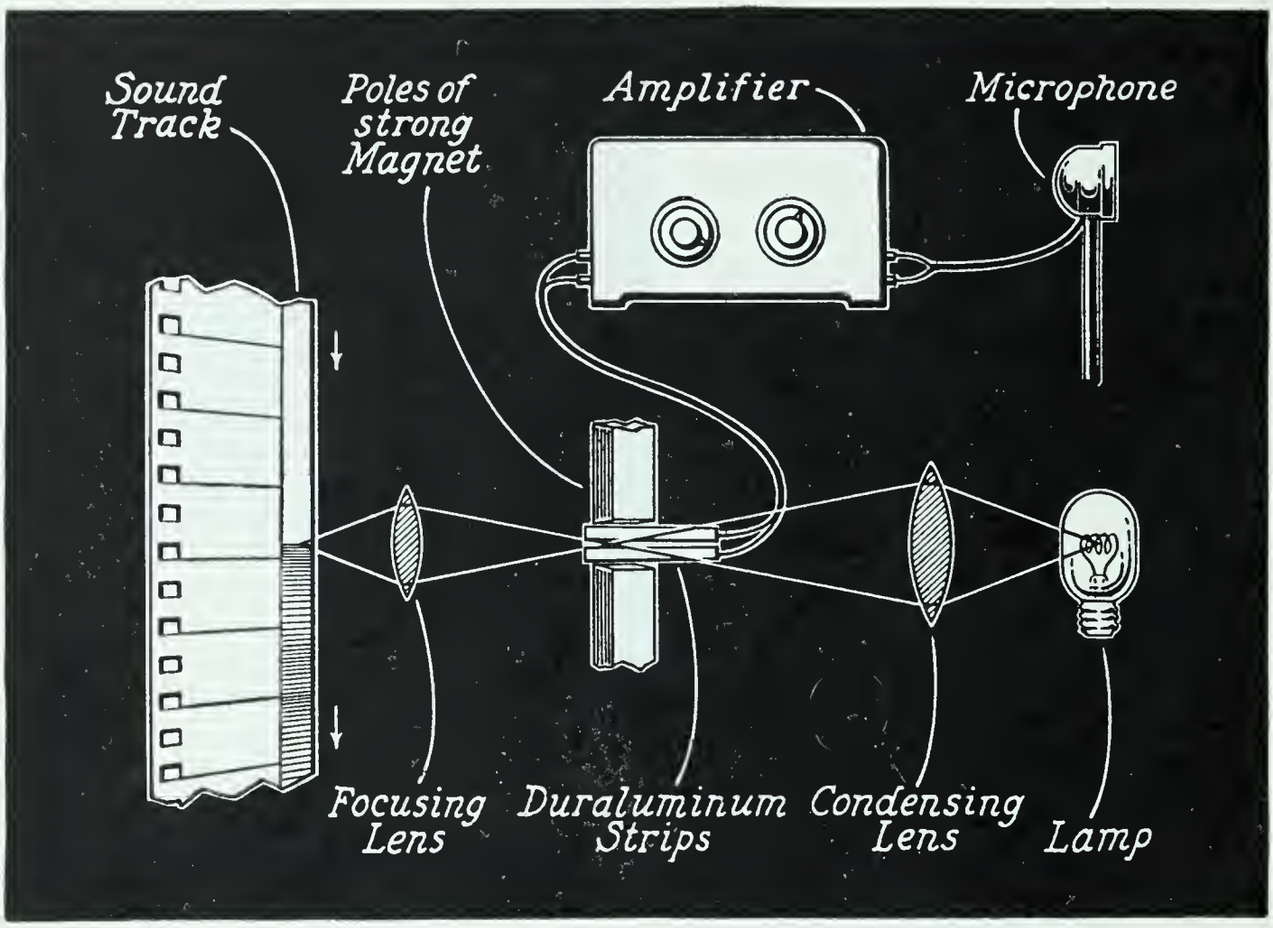


Courtesy Philco Radio and Television Corporation

A photoelectric reproducer for phonograph recordings showing the arrangement of the light, the mirror, and the photoelectric cell.

As used in the phonograph, the photoelectric cell makes it possible to reduce still further the amount of pressure needed between the stylus and the record. In one type of phonograph which uses the photoelectric cell, a sapphire stylus is suspended so that it practically floats in the wobbly groove of the record. The next part of the process is "done with a mirror." A tiny mirror attached to the stylus swings from side to side on its axis as the sapphire moves along the uneven groove of the record. A beam of light is directed upon the mirror, and the reflected beam flashes on and off a photoelectric cell according to the movements of the stylus. Consequently, the flow of current generated by the photoelectric cell varies in a similar manner. This current is amplified by vacuum tubes and is used to operate the loud-speaker.

"Sound-tape transmission" is a new method used in radio for recording programs which are to be rebroadcast later. A photoelectric cell is again used in helping to reproduce the original sound. Instead of making a record of the program on a flat disk as in ordinary recording, the sapphire stylus of the recording device is used to cut a sound track into a special kind of tape. This tape is similar to motion-picture film except that it has a thin opaque surface instead of a coating which is affected by light. During the recording operation, the tape moves at a constant speed while the sapphire cuts perpendicularly into it to varying depths. The stylus, of course, leaves a transparent sound track as it cuts through the opaque surface. During reproduction of the sound, the tape is moved at a constant speed just as it was during the recording. A beam of light is passed through the transparent sound track and then upon a photoelectric cell. The variations in intensity of the light going through the tape enable the photoelectric cell, amplifier, and loud-speaker hookup to reproduce faithfully the recorded sounds.



This diagram sets forth the chief steps by means of which sound is "photographed" in making sound pictures.

There are obvious advantages to this type of recording. In the first place, it eliminates wear due to the friction between a stylus and the record. Secondly, since the tape can be spliced, it is possible to cut out unwanted portions, to insert new portions, or to rearrange the order in which parts of the recording are reproduced. This kind of cutting and editing has always been possible in the recording of action by motion-picture film but impossible with the recording of sound by means of phonograph records.

The phonograph and motion-picture projector were combined to produce the first sound motion pictures, or "talkies." The music and dialogue were recorded on phonograph records and reproduced behind the screen while the projector flashed the pictures upon the screen. It was necessary to synchronize the two operations very accurately. You can easily imagine the difficulty when the film broke. Another objection was the constant nuisance of having to change records periodically. Many amusing mishaps occurred—singers went through all the motions of singing while silence prevailed; speech sometimes followed a short interval after the facial expressions that it should have accompanied. Consequently, it was desirable to develop a system by means of which

the sound and the pictures could be reproduced simultaneously from the same machine.

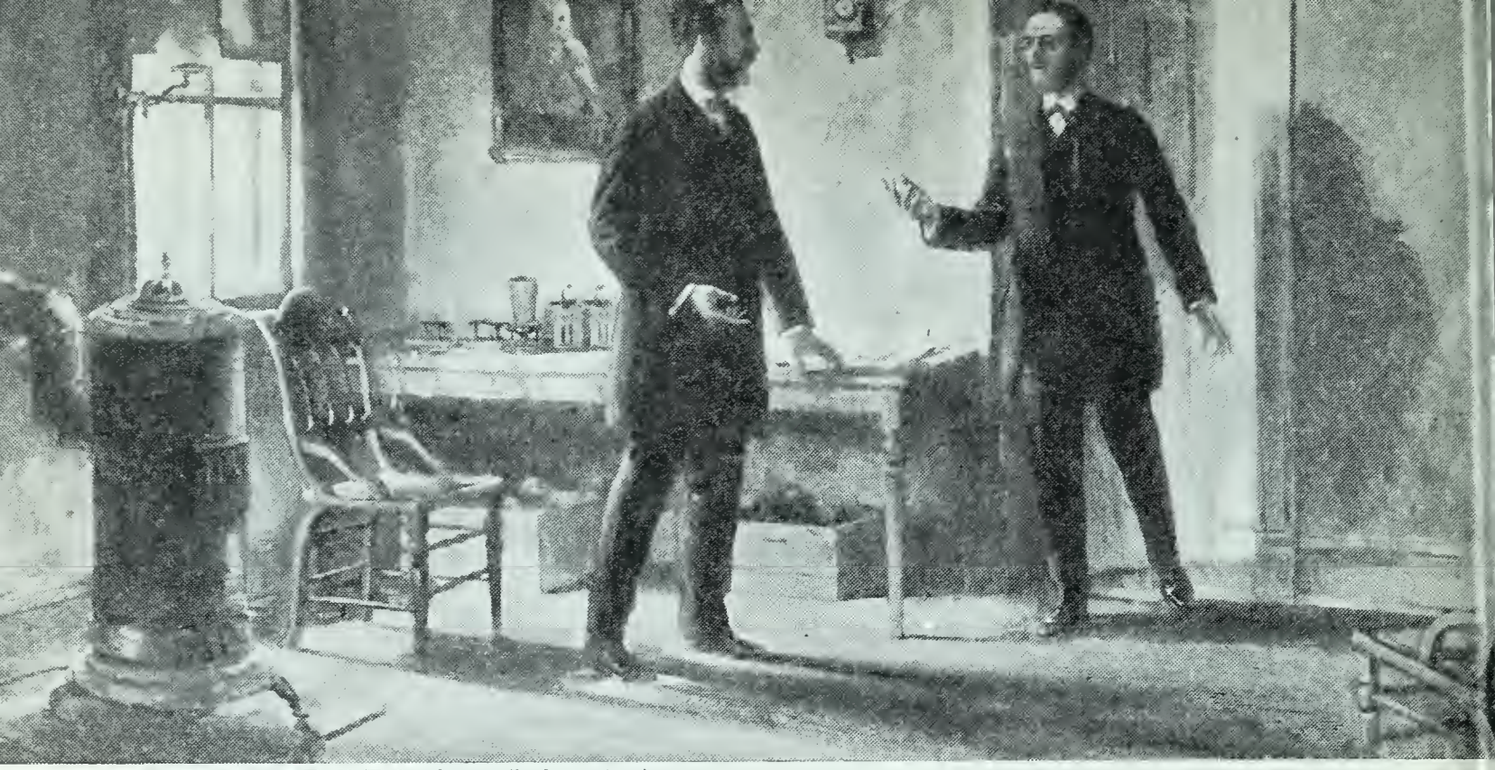
Modern sound pictures are projected from films upon which the sound as well as the action has been recorded. An examination of such films shows the sound track along one margin. Refer to the diagram and you will see how man has succeeded, in a sense, in photographing sound. The actors' voices and any musical accompaniment produce sound waves which enter a microphone. Here they set up a pulsating electric current in a circuit which includes an amplifier. After amplification, the current passes through very thin strips of duralumin—an alloy of aluminum, copper, magnesium, and manganese. The duralumin strips are spaced a very small fraction of an inch apart and are surrounded by the poles of a strong magnet. The magnet plus the metal strips form the *light valve*. Forces of attraction and repulsion are set up between the field of the magnet and the magnetic field which surrounds the strips when the pulsating current flows through them. These forces cause the strips to move back and forth bringing them alternately closer together and farther apart. The size of the opening between the two strips is thus regulated by the varying intensity of the electric current, and this in turn is controlled by the sound waves that enter the microphone.

The photographic record of the sound—that is, the sound track—must be made with light. A lamp provides the light which is properly concentrated by a condensing lens upon the slit between the strips of duralumin. The amount of light which gets through the opening varies with the size of the slit, which, as we have seen, is controlled by the sound being recorded. After passing through the light valve, the light waves are focused upon the film by another convex lens. When the film is developed, the sound track shows up as light and dark bands of various widths.

The reproduction of the sound from the film is similar to its reproduction from the sound-transmission tape. Light is concentrated upon the sound track and that which gets through falls upon a photoelectric cell. The resulting variable current is amplified and then converted back into sound by loudspeakers.

Exercises for Problem Study and Review

1. How is a modern recording made and transferred to many permanent records?
2. What scientific principles are involved in electrical methods of



Courtesy Bell Telephone Laboratories

Watson enthusiastically responds to Bell's famous summons. After forty weeks of building and rebuilding, their telephone finally "talked."

recording and reproducing sound but were not used in the older mechanical methods?

3. What disadvantages did the application of these principles overcome?

4. How does the moving-coil type of loud-speaker work?

5. Explain the action of the photoelectric cell. Give examples of its application, including an explanation of its use in phonographs.

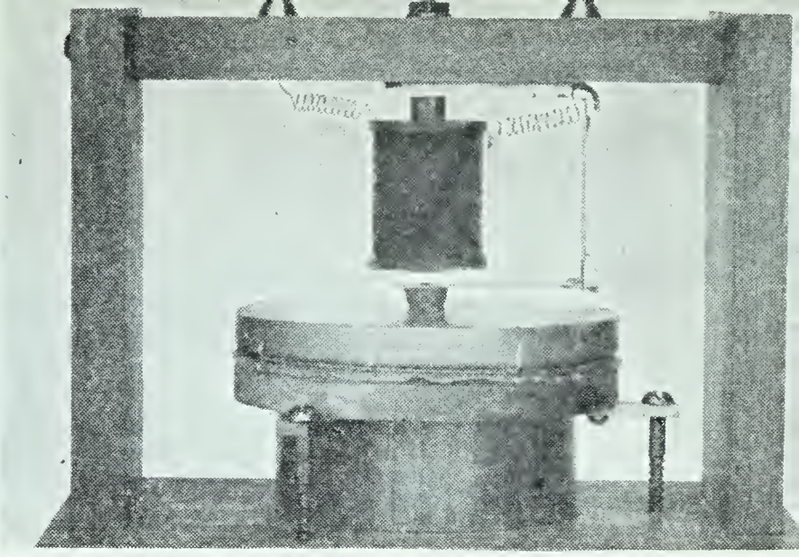
6. What is sound-tape transmission? What advantage does it contribute?

7. How are sound tracks made and used to reproduce sound for motion pictures?

Problem 5: How do we transmit and receive sound?

It is probable that the average citizen in the United States is better informed on domestic and world happenings than the average citizen of any other nation on earth. This happy situation has resulted largely from our highly developed systems of communication and the interlocking services which they give. In our country we have more than two million miles of telegraph lines and more than twenty million telephone installations, and the 1940 census showed about forty-five million radio sets in use. How many members in your class can remember when their homes did not have at least one radio?

Communication has not always been so simple and direct as it is today. Throughout the ages, man has been faced with the need



Courtesy Bell Telephone Laboratories

This model of Bell's first telephone is a duplicate of the instrument through which speech sounds were first transmitted electrically in 1876.

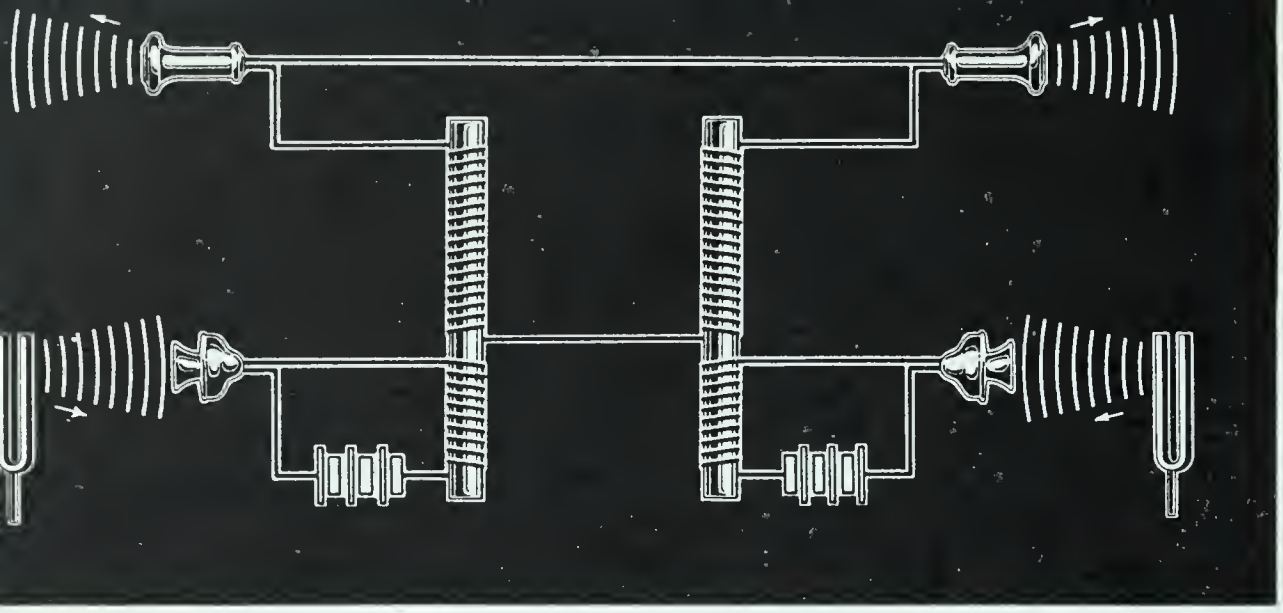
for rapid and reliable means of communication and has developed many devices to accomplish this purpose. Beacon fires and smoke signals, semaphores, heliographs, wigwagging, drum beats, and many other methods were developed for sending and receiving messages without the necessity of any messenger, such as man, carrier pigeon, or other animal. Today communication is carried on chiefly by electrical devices. In this problem we shall investigate how the telephone and the radio enable us to send the sound of our voices across land and sea. As a preliminary to the study of this problem, it would be well to review how the telegraph and the electric bell operate (pages 157-159).

• WORDS, WAVES, AND WIRES

Alexander Graham Bell was not the first man to think of sending speech sounds over electric wires, but it was he who first demonstrated to the world a practical way of turning this dream into reality. The principle of the telephone was worked out in 1875, and on March 10, 1876, his experiments culminated in those memorable words, "Mr. Watson, please come here; I want you," which Bell telephoned to his assistant two flights of stairs below him. Bell exhibited his telephone at the Centennial Exposition in Philadelphia in 1876, but few people foresaw any practical future for it; it was regarded more as a toy. There were only 234 telephones in the entire country in 1877.

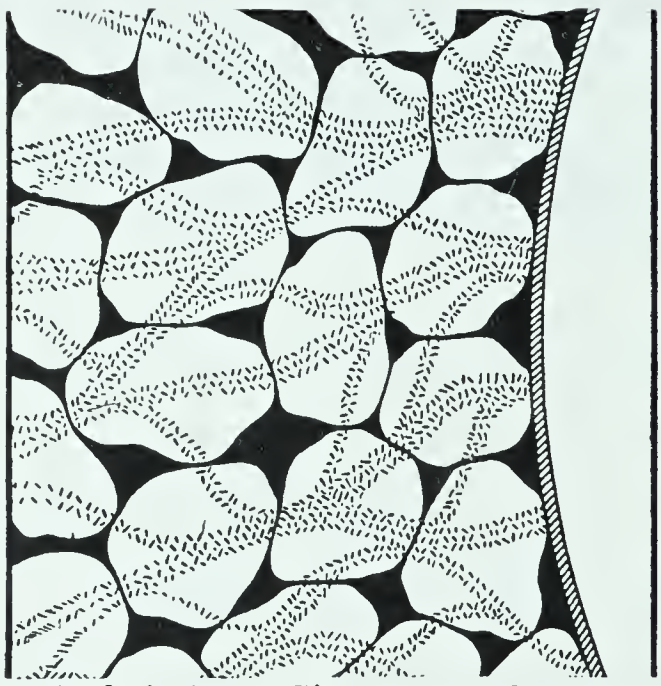
Of course you know that no sound actually passes over a telephone line. At one end of the line, sound waves are changed into electric currents which pass over the wire to the other end of the line, there to be changed back into sound. The essential parts of a telephone system are transmitters, receivers, a source of electric current, and a line to carry the current from one station to an other. A simple telephone system is illustrated on the next page.

The transmitter changes sound waves into a fluctuating electric current. When words are spoken into the transmitter, the sensitive diaphragm vibrates much as the human eardrum vibrates when compressions and rarefactions in the air strike it. Behind



How is the principle of electromagnetic induction involved in this simple telephone system?

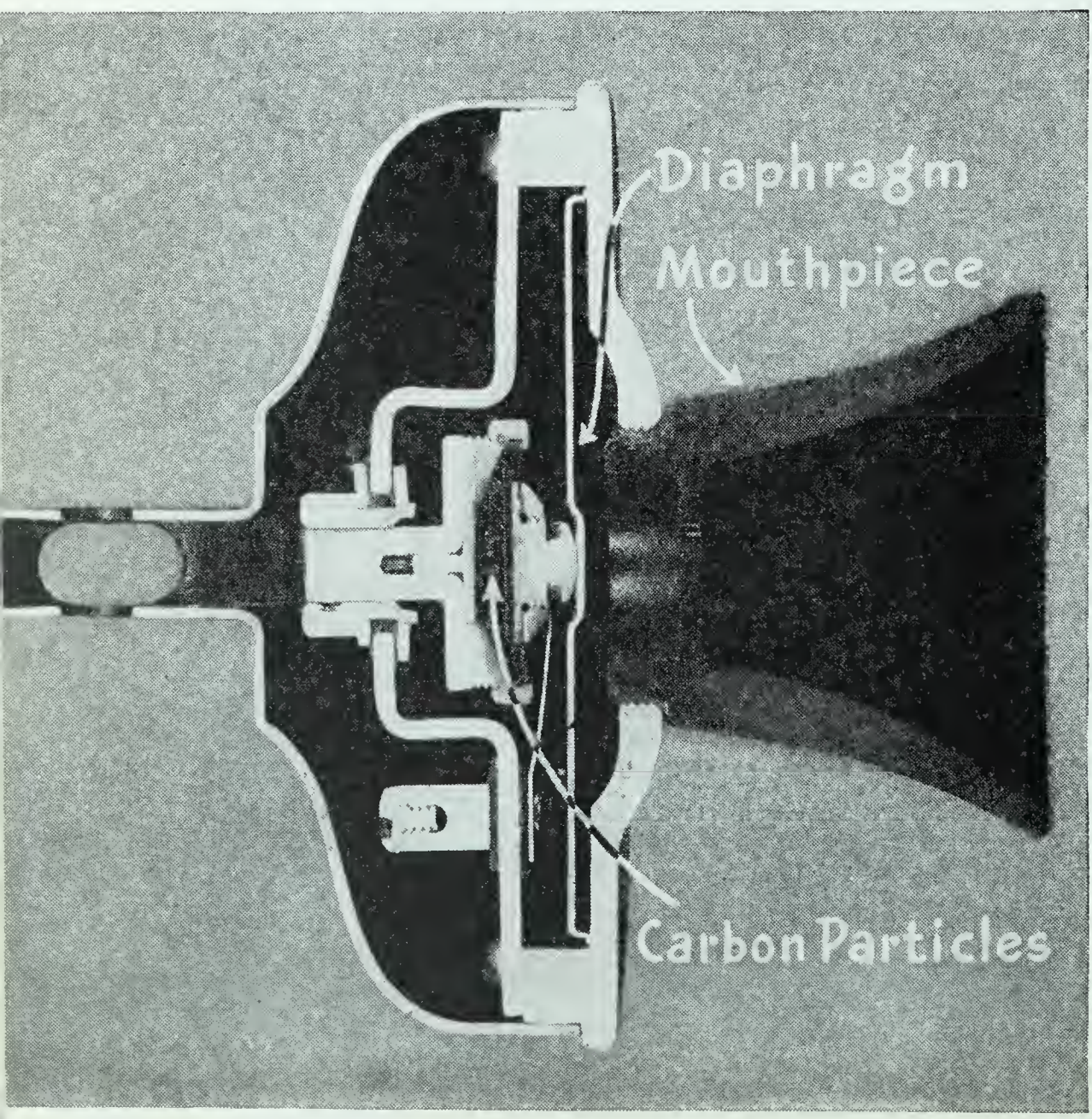
Speech into a telephone transmitter vibrates the diaphragm. When the carbon grains are closely packed, more current can pass through. Each time the diaphragm springs back, the grains are loosely packed and less current can get through.





Courtesy Bell Telephone Company

Left below: The parts of a telephone transmitter.
Right below: The transmitter and the receiver of this type of telephone are really separate units.



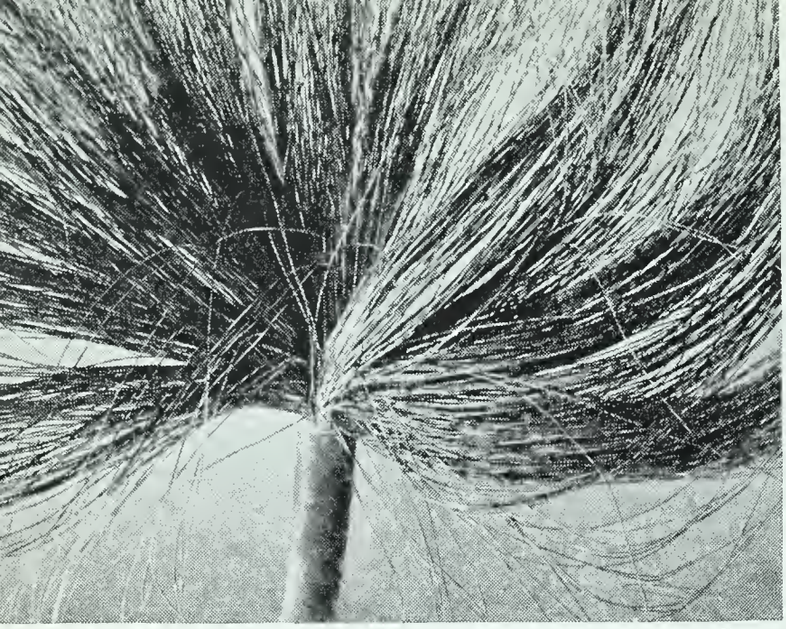


the diaphragm is a small box filled with hard carbon granules, through which the electric current from the battery must flow. When the diaphragm is forced toward the box by a compression, it crowds the carbon grains closer together; this decreases the electrical resistance of the carbon and the current increases. When the diaphragm springs back during a rarefaction, electrical resistance increases as the carbon particles loosen up again and a smaller current flows through. The illustrations on page 606 show the intensity of the electric currents through the closely packed and loosely packed carbon granules. Thus we see that the back-and-forth movements of the diaphragm cause a varying electric current to pass through the transmitter and out over the wires to the receiver. The fluctuations of this current in regard to frequency and intensity are regulated by the characteristics of the sound waves that enter the transmitter.

The receiver changes a varying electric current into sound waves. The ordinary telephone receiver usually consists of a hard-rubber case containing a U-shaped permanent magnet. There is a coil of many turns of fine wire wound on each pole of the magnet. A thin, flexible steel disk is supported so that its center is very near the poles of the magnet, but it does not quite touch them.

As the variable current from the line passes through the coils, the strength of the magnetic field fluctuates accordingly. When the field strengthens, the disk is pulled toward the coils; when the field weakens, the diaphragm springs back. These vibrations of the steel disk correspond to the variations of the electric current in the line. They set the air into vibration, also, and by this means are carried to the ear of the listener, who hears an accurate reproduction of the voice of the speaker at the other end of the line.

Connection between the transmitter and the receiver is made at the telephone central. The transformer and receiver of a particular telephone are coupled to the telephone line by means of a transformer and to the central office by a pair of wires. These wires run through cables supported from telephone poles or conducted through conduits in the ground. Early telephone cables were one-inch lead or iron pipes carrying less than a dozen wires embedded in gutta-percha or paraffin. Today, cables carry as many as 4,200 wires in a space no larger than a man's wrist. Each wire is coated with paper to enable it to carry voice waves without interference from its neighbors. When you call central and give the number you wish to call, the operator connects your wire with the one leading out to your party. If you use a dial telephone, com-



Courtesy New Jersey Bell Telephone Company

Top: These are voice highways. You use them when you telephone. They are tiny strands of copper covered with lead. Each wire is covered with paper so that it can carry voice waves without interference from its neighbors.

Bottom: This is the way busy city streets looked sixty years ago. Today underground cables keep telephone wires out of sight.

Courtesy Bell Telephone Laboratories



plicated machinery makes all the necessary connections and rings your party automatically. Trunk lines connect all the districts within large cities and spread out from one city to another in an amazing network of voice highways. By combining the services of telephone and radio, it is now possible and even commonplace to sit in your home or office and talk directly with persons in Europe, Asia, Africa, Australia, or South America, on ships at sea, and in aircraft aloft. About 93 per cent of the world's telephones can be reached from the telephone in your home.

• WORDS AND WAVES WITHOUT WIRES

Radio has been described as the greatest invention since that of the printing press. To find out who invented it, however, you would have to read accounts of the work of half a dozen or more individuals—men whose names might suggest a roll call of the nations. French, English, German, Italian, and American scientists have contributed ideas and gadgets, theories, and fundamental discoveries; they have cooperated for improvement and progress. During the years 1896 to 1920, they took us

from dots and dashes to speech and music by means of crystal sets with head receivers; in twenty years more they took us from crystal sets to high-fidelity reproduction on loudspeakers, television, and frequency modulation. The radio-manufacturing and broadcasting industry has become one of the great enterprises of modern times. Anyone can acquire at least an elementary understanding of what goes on in that magic box—your radio. Perhaps you would like to know how the words, music, and even the images of the radio performers go "on the air."

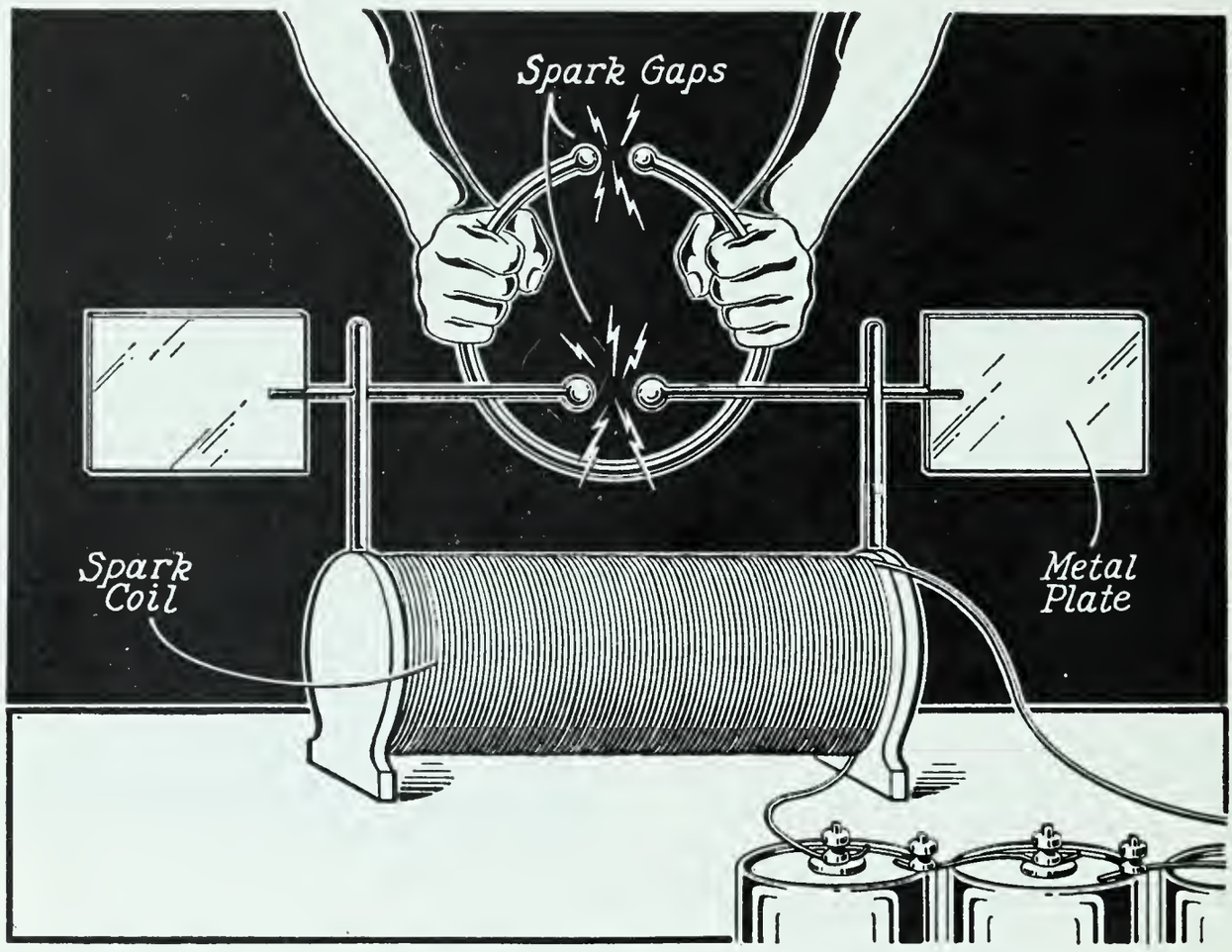


Courtesy Westinghouse

From this 700-foot broadcast antenna go forth the radio waves that are picked up by receiving sets.

Let us begin with waves. You have had experiences with sound waves, water waves, and light waves. You know that it seems impossible to have a wave motion without some medium in which to produce the waves. In traveling through a vacuum, which so far as we know is "empty" space, light seems to do the impossible. Many scientists believe that some indetectable medium exists and permeates all space—even the space between the molecules of gases, liquids, and solids, and the space in a vacuum. This medium, called the "ether," is presumed to be what transmits light waves, X rays, ultraviolet and infrared rays, and radio waves—all at the same rate of about 186,000 miles a second. These, you will recall, all belong to the electromagnetic spectrum.

In radio, metric units are used. In the metric system the velocity of radio waves is about 300,000 kilometers per second. As you know, the speed of a wave divided by its wave length gives its frequency. Each broadcasting station has its own wave length (stated in meters) and its own frequency (stated in kilocycles per second). For example, a well-known station, WEAF, has a frequency of 660 kilocycles. The speed of a wave, 300,000, divided by the station's frequency, 660, equals 454, its wave length in meters. WABC has a frequency of 880 kilocycles. What is its wave length?

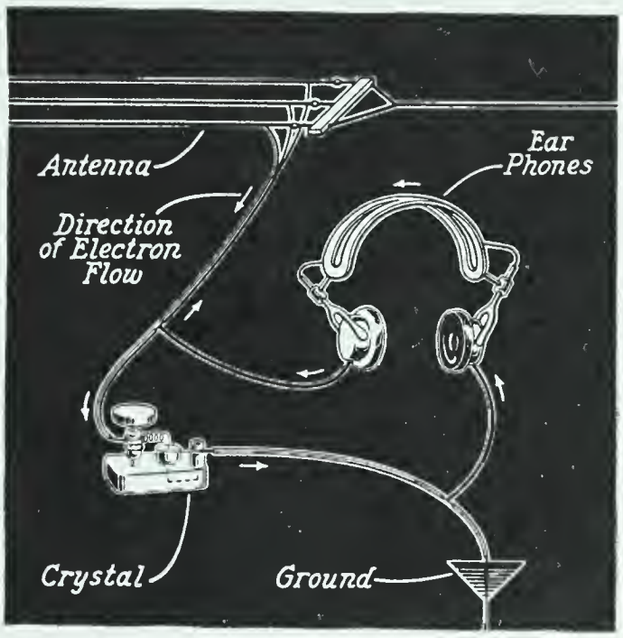


In Hertz's experiment, the spark across the gap of the coil broadcast electromagnetic waves which caused a spark to discharge across the gap in the loop. Metal plates attached to the coil acted as the "antenna" and intensified the waves. The loop was "tuned" by adjusting its size.

Wave lengths used in ordinary broadcasting range from about 545 meters (frequency, 550 kilocycles) to 200 meters (frequency, 1,500 kilocycles). To avoid interference, wave lengths and power ratings are assigned by the Federal Communications Commission; to some extent, international agreements are also observed. The frequency of radio waves is too high to affect the human ear and they are known as *radio-frequency* waves. Waves of frequency low enough to be received by the ear are described as *audio-frequency* waves. Radio waves have many times the wave length of light and hence do not affect the human eye.

Radio waves were predicted several years before a way was found to produce them. This was done in 1867 by James Clerk-Maxwell, a young mathematician of Edinburgh, Scotland. Here is a fine example of a highly mathematical theory in pure science whose applications have become commonplace in modern living. Radio waves were first produced in 1888 by Heinrich Hertz, a

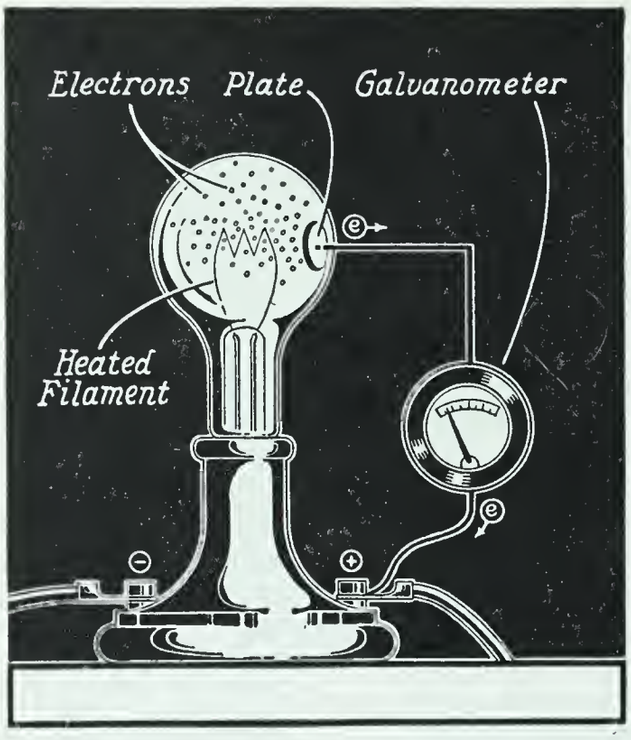
young German scientist. In testing Maxwell's hypothesis, Hertz shot electric sparks across the gap of a spark coil and found that as he did so, electromagnetic waves were set up in the surrounding ether. He found that when an open loop of wire of certain size was held near the spark coil, a spark would jump the gap between the ends of the loop. Here were the first radio transmitter and the first radio receiver.



The crystal acts as a "one-way street" for electrons.

The disturbance which causes these waves is the to-and-fro surging of electrons in the electric spark. As they oscillate (move rapidly) first in one direction and then in the other, electromagnetic waves pass outward in all directions. If one side of the spark gap is connected to an aerial and the other side to the ground, electrons in the aerial also surge to and fro. This increases the size of the oscillator, and trains of waves having enough energy to be detected many miles away are sent out when the key is closed. The length of time the key is closed can be used to designate dots and dashes for communication by radio telegraphy.

The reception of radio waves required an aerial with a detector between the aerial and the ground. When the electromagnetic waves strike the aerial, they cause its electrons to oscillate with the same frequency as those in the aerial at the sending station. However, the current is too weak to be detected by a loop of wire with a spark gap in it, and special devices are used as detectors. Using an improved form of a device called a *coherer,* Marconi successfully received radio messages across the Atlantic Ocean in 1901. However, crystal detectors soon replaced the coherer. Crystals of *galena,* which is natural lead sulfide, were widely used. They act like one-way streets for electrons, allowing them to pass through in one direction but not in the other. When connected as shown in the above illustration, the crystal detector lets electrons pass through it to the ground, but when they surge the other way they cannot get through the crystal



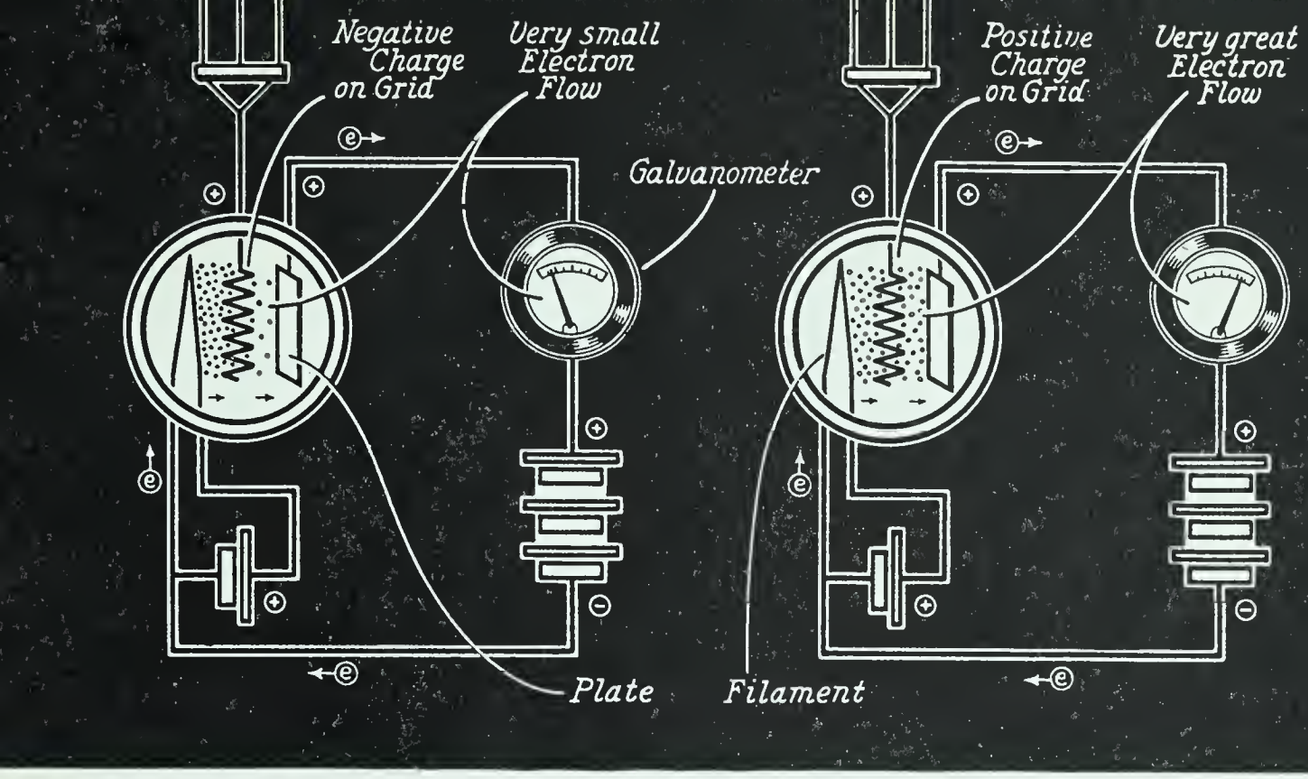
What does the deflection of the galvanometer needle indicate? This phenomenon is known as the Edison effect.

and must go around through the earphones. Thus the rapidly alternating current in the antenna becomes a pulsating, direct current through the sensitive receiving phones. Here the changing electromagnetism causes the diaphragm to vibrate just as in a telephone receiver and to sound out dots and dashes just as they were sent by the sending station.

The development of the three-electrode vacuum tube has made radiotelephony possible. Radiotelegraphy and radiotelephony differ much in the same way that the telegraph and the telephone differ. Telegraph messages are sent by dots and dashes, while telephone messages are sent by changing voice waves into pulsating electric currents which travel over wires. Radiotelegraphy messages are also sent in code, but in radio telephony, sound waves are changed into electromagnetic waves and broadcast through the ether to the receiving set, where they are received and changed back into sound waves. The waves produced by a spark coil are not satisfactory for broadcasting the voice, and other methods of producing and controlling the oscillations of electrons have been devised. The continuous, high-frequency wave needed for broadcasting speech and music is called the *carrier wave;* it may be produced by a high-frequency, alternating-current generator, but it is more commonly produced by the three-electrode vacuum tube.

Soon after he invented the electric lamp, Edison discovered that electrons "boil off" from the hot filament into the space around it. When he put a plate inside the lamp bulb and gave it a positive charge by connecting it to the positive wire leading to the lamp, a small current flowed across the space from the filament to the plate and back into the main circuit. When the plate was connected to the negative wire, no current flowed. How would you interpret these observations?

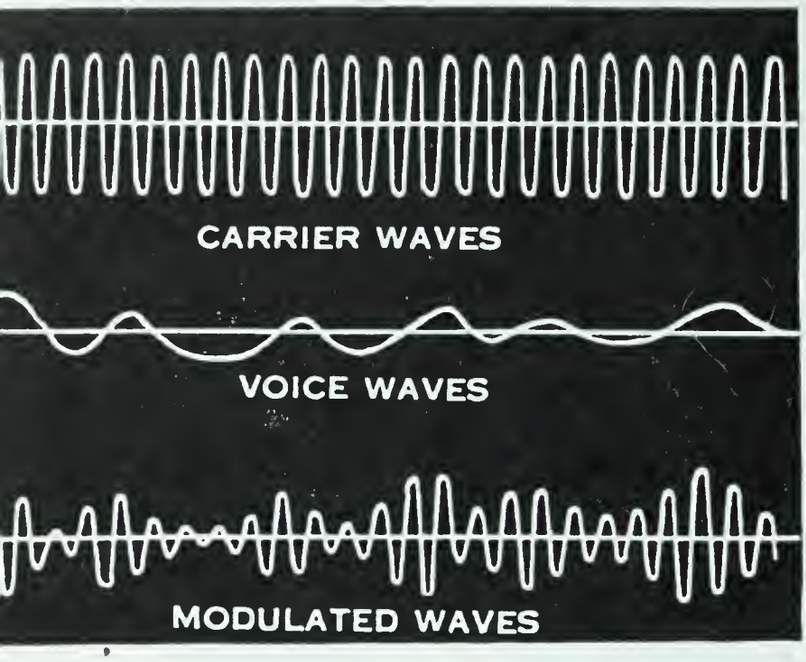
Sir John Fleming, an English scientist, adapted the Edison



Study this diagram to learn how the three-element vacuum tube works.

effect to radiotelegraphy and used it as a detector. His invention was known as the Fleming valve (for electrons) and became widely used because it was more sensitive than the crystal detector. A few years later, Dr. Lee De Forest, an American, added still another improvement by inserting a small *grid* between the filament and the plate, thus giving us the fundamental principles of the vacuum tube which made radio broadcasting possible. Vacuum tubes may be used as oscillators, detectors, or amplifiers.

If you open a vacuum tube and examine it carefully, you will see that it contains three elements. They are: (1) the filament; (2) the grid, a network of fine wire; (3) the plate, a hollow cylinder surrounding the grid. Four prongs at the bottom of the tube connect these elements to the external circuits—one connection goes to the grid, one to the plate, and two to the filament. When the filament is cold, no electrons are emitted from it, but when heated by a flow of current from the "A" battery, electrons "boil off." These are repelled from the filament and attracted to the plate, which is connected to the positive terminal of the "B" battery. Thus there is a steady flow of electrons from the filament to the plate and through the plate circuit. What do you suppose would happen, now, if the grid were given a negative charge? A positive charge? The grid is an important means of controlling the plate current. When the grid is positive, it helps pull electrons from the filament and speed them on their way to the plate; thus the plate current is increased. When the grid is negative, it repels electrons back to the filament and prevents them from going to the plate; thus the plate current is decreased. Small variations in the electrical condition of the grid produce large changes in the plate current. Thus the tube may act as an amplifier.

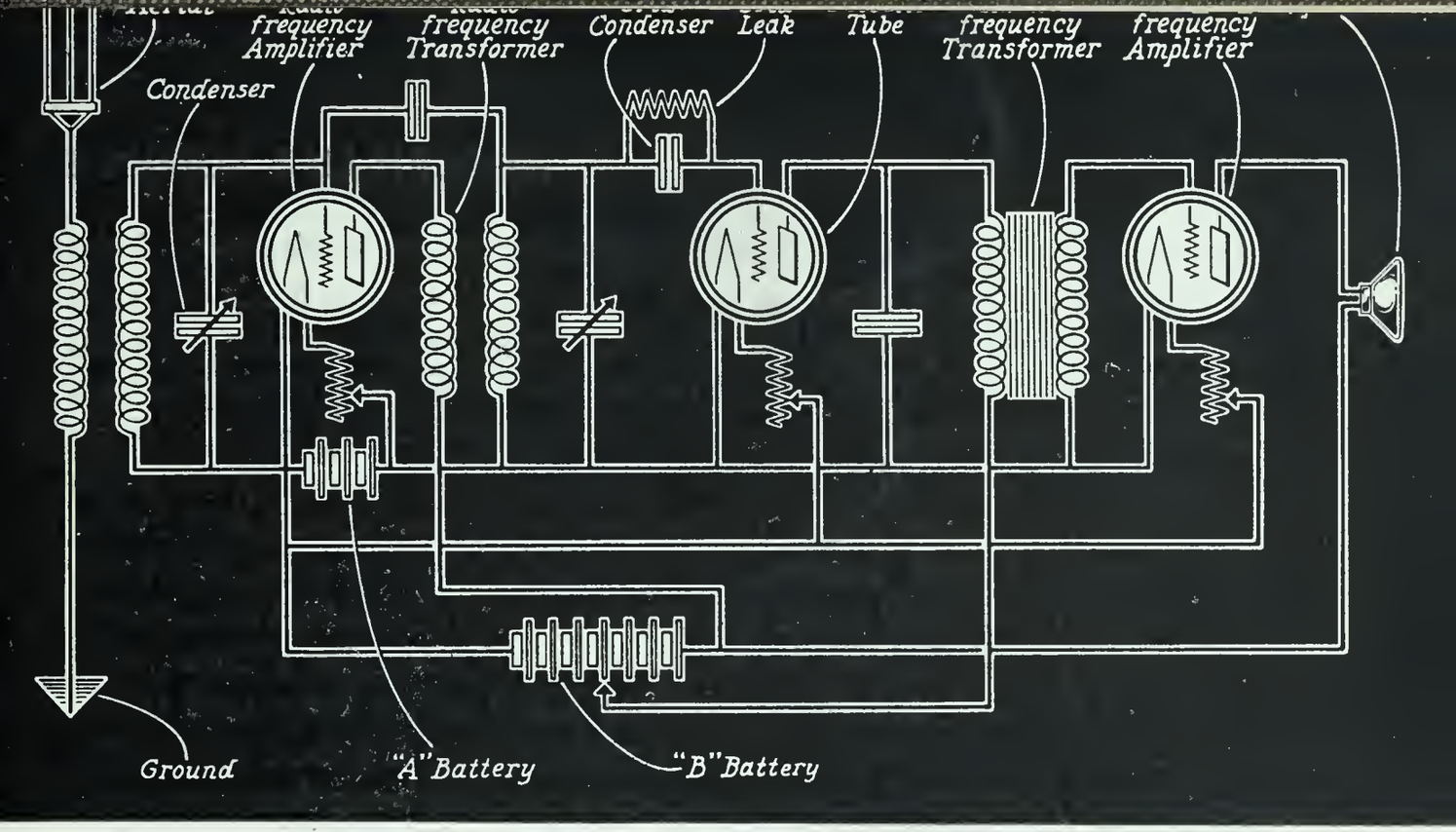


Modulated waves are produced by superimposing sound waves on carrier waves.

When the vacuum tube is used as an oscillator, the grid circuit is connected in such a way as to produce a high-frequency, pulsating current in the plate circuit. By means of a transformer connected to the antenna, the rapidly pulsating plate current produces an oscillating current in the antenna circuit. Thus the necessary high-frequency carrier wave is produced. However, it must be modified before it can be broadcast and received by radio sets—the voice wave must be superimposed on it. This is done by connecting the microphone into the plate circuit. When sound waves strike the microphone they are changed to electrical impulses and are added to the already pulsating plate current. The frequency of the carrier wave is unchanged, but the amplitude, or wave form, is altered and the result is called a *modulated wave.* A comparison of the carrier wave, sound wave, and modulated wave is shown in the illustration. It is the modulated wave which is turned into waves of audio frequency and is amplified by the vacuum tubes of your radio set.

When the vacuum tube is used to detect radio waves and turn them into waves of audio frequency, the antenna is connected to the grid. As electromagnetic waves from the broadcasting station cut across the aerial wire, a feeble alternating E.M.F. is impressed on the grid. As electrons surge to and fro, the grid is first positive and then negative. The varying charge on the grid alternately helps and hinders the passage of electrons from the filament to the plate. Thus the feeble antenna current is amplified in the plate circuit. Furthermore, the current that flows in this circuit is a varying, direct current—the kind needed to operate earphones or a loud-speaker. Before entering the earphones or speaker, however, the plate current from the detector tube is usually sent through a step-up transformer and into the grid circuit of one, two, three, or more tubes which amplify it still more.

The electromagnetic waves sent out by several broadcasting sta-



This diagram shows the parts of a simple battery set and how they are arranged in the various circuits included in this type of radio receiver.

tions are cutting your antenna wire at the same time, and so there are several alternating currents set up in it. To select the station you wish to listen to, you must "tune in." This consists usually of changing the position of a variable condenser, which determines the particular frequency to which the set will respond. The result is that only one of the alternating currents in the antenna gets through the circuit in the radio; all others are excluded. Turning the dial changes the variable condenser to a different position, and the set responds to a different frequency—a different alternating current gets through, and you have a different station. This is really a case of resonance or sympathetic vibrations similar to that demonstrated by striking one tuning fork, which can in turn set a second fork into vibration if the vibration rates of both forks are the same.

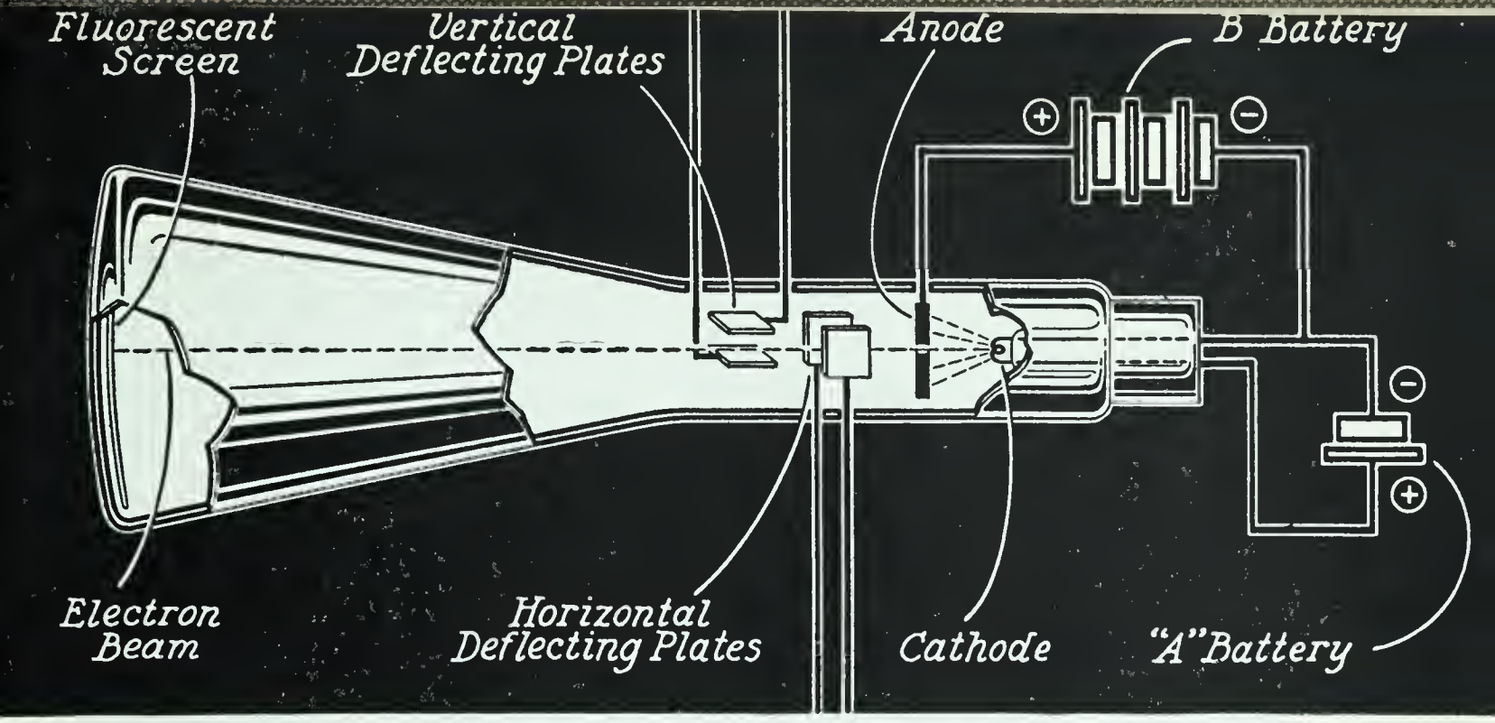
Study the diagram of a simple battery set above. See if you can trace through the various circuits and tell what happens at each step from the aerial to the speaker. Most radio sets, however, are "all electric" and are operated simply by plugging into an electrical outlet. Nevertheless, the basic principles are the same. The essential difference is that the filament of each tube is heated by alternating current, thus eliminating the "A" battery, and the current for the plate circuits is supplied by vacuum tubes which act as rectifiers—that is, they change A.C. to D.C.

Chain broadcasting combines the telephone and radio. Programs are produced in the main studio and are sent out over regu-

lar or specially designed long-distance telephone circuits to perhaps a hundred or more local stations. The local station feeds the current from the telephone line into its transmitters, and the program goes "on the air." The difficulties that had to be overcome to make chain broadcasting feasible involved modifications of the lines provided for general telephone service. In an ordinary long-distance telephone circuit, frequencies of not more than 3,000 cycles per second are used. In connecting radio stations by wire, however, a range of 75 to 5,000 cycles per second must be handled in order to meet fairly well the requirements of broadcasters for a high-grade network service. Recently, circuits 1,200 miles long and transmitting frequencies up to 15,000 cycles using standard telephone facilities with special terminal equipment have been demonstrated.

Another problem that had to be overcome resulted from the fact that vibrations of different frequencies travel with different speeds over the transmission equipment. For various reasons, both the low notes and the high notes may lag behind those of medium pitch. This means that if a correction were not made, some notes of music would get to your speaker ahead of others, although they started out together. High fidelity would be impossible because the fundamentals and overtones would be out of step; some music might even be badly distorted. In short-distance telephone circuits, the difference is not appreciable; in long-distance telephone circuits, whether for radio programs or ordinary conversation, the waves of different frequencies are amplified and put "in step" by sets of automatic equipment spaced from 50 to 300 miles apart. As a result, reproduction is nearly perfect. The American Telephone and Telegraph Company has a demonstration on sound during which recorded music can be reproduced directly through a loudspeaker on the stage or after it has traveled over wires, for example, from Atlantic City to New York, to Cleveland, to Chicago, to Pittsburgh, to Philadelphia, back to Atlantic City, and to the loudspeaker. If you are listening with your eyes closed, you are unable to tell whether the music has traveled around a telephone circuit of 3,000 miles, or whether it has traveled only 15 feet across the stage. This is a remarkable demonstration of what radio and other sound engineers have done to make the transmission and reception of speech and music more accurate and more enjoyable for all of us.

Public-address systems as commonly used in auditoriums and to announce outdoor events also operate by means of vacuum



This diagram explains the principle of the kinescope—the "loud-speaker" of the television receiver.

tubes. Since these devices do not broadcast sound waves but only amplify them, no carrier wave is needed. All that is necessary is to feed the sound waves into a microphone connected into the grid circuit of a three-element vacuum tube. As usual, this causes a varying charge on the grid and, in turn, a varying plate current. The plate current may be amplified still more by sending it into the grid circuit of a second tube before it is conducted to one or more loud-speakers. Here, through the electromagnetism produced, the cone of the speaker is caused to vibrate accordingly and set up sound waves in the air identical with the original ones but with more energy.

Television is a form of radio by means of which images as well as sounds can be broadcast. The television receiver is really a "two-in-one" instrument. One part of it is an ordinary receiver for the "sound" portion of the program, and the other is a specially designed receiver for the "sight" portion of the program. Fortunately there is no difficulty in synchronizing sight and sound in television, although the audio frequencies range from 50 to 15,000 cycles, while the video frequencies (those which can be converted into pictures) range up to 4,000,000 cycles. Television is rapidly moving along toward stability, but there are still certain handicaps to be overcome before it is accepted as widely as the radio for home entertainment and educational uses. Undoubtedly, however, the future will see a greatly improved and extended type of television—perhaps in natural colors. The high cost of present television is another factor which limits its use.

One of the successful methods of television utilizes the iconoscope, a device which corresponds to the microphone in sound-



Courtesy RCA Victor Manufacturing Company, Inc.

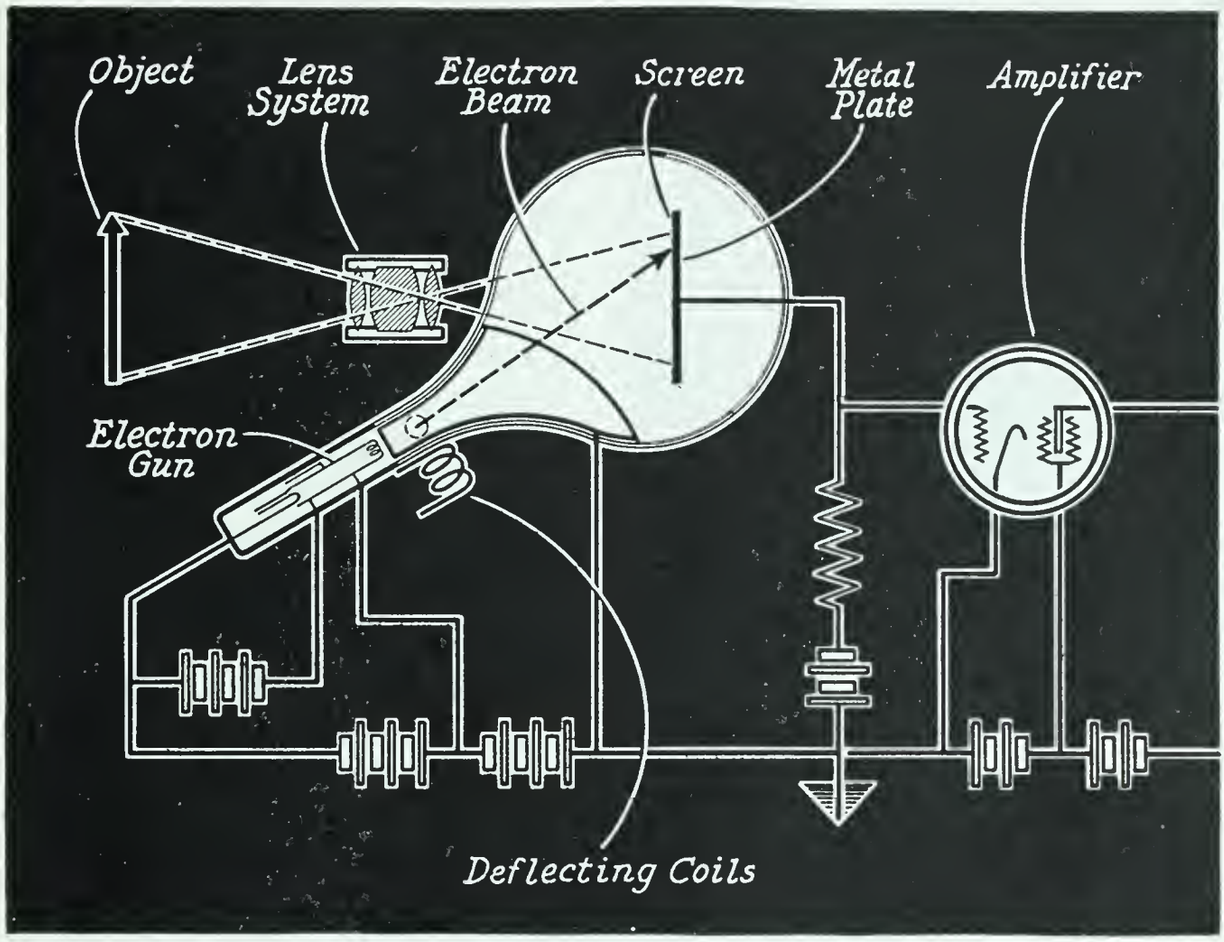
Above is shown an iconoscope tube —the "microphone of television."

broadcasting. This is a large vacuum tube in which is placed a screen for receiving the image to be transmitted. The screen is made of an insulating material, such as mica, which on one side has a metal plate and on the other a coating composed of about 200,000 tiny, insulated globules of a light-sensitive material—really 200,000 microscopic photoelectric cells. The high-voltage cathode gives off electrons and drives them in a beam toward the screen. By means of two pairs of coils suitably placed—one pair above and below, the other pair on either side—the electron beam can be magnetically deflected horizontally and vertically so that it will strike at any desired point on the screen.

The image of the scene to be broadcast is focused by a lens system onto the light-sensitive surface of the screen. This causes electrons to be "kicked out" of the globules in proportion to the intensity of the light striking them. The globules thus acquire positive charges. Electrons are drawn up into the insulated metal plate, giving it a negative charge. The electron beam now sweeps across the screen and supplies electrons to replace those lost by the globules; this also discharges the metal plate. The returning electrons from the plate form a current whose intensity is proportional to the intensity of the light received in the image. This current is then amplified and transmitted at video frequency.

By means of the magnetic deflecting fields, the electron beam is made to move from one side of the screen to the other in successive parallel, slanting lines, the adjacent paths being spaced so as to just overlap. In this process, called *scanning,* the electron beam crosses the image about four hundred times in one-thirtieth of a second. The standards recently set up by the Federal Communications Commission call for 525 scanning lines a picture.

At the television receiver, the image is reproduced in similar fashion by means of the kinescope. This device corresponds to the loud-speaker in ordinary radio. The kinescope is a vacuum tube which has a fluorescent coating on the inside of the large end to serve as a screen. Electrons bombard this screen and cause it to



The iconoscope or television camera uses electrons to form the image of the scene to be broadcast.

glow with an intensity proportional to the intensity of the electron bombardment, which in turn is controlled by the intensity of the video-frequency waves received. Deflecting magnetic fields make the electron beam move across the screen in the same manner as in the iconoscope, and the signals sent out at the sending station cause the deflection to synchronize with that at the transmitter. Thus the image received will be found to correspond with the image that was sent. See the illustration on page 617.

The reality of television, as with the movies, depends upon an optical illusion, persistence of vision. In the movies, you see a series of stills—in television, you see a succession of pictures that actually move as they are being drawn by the lightning strokes of the electronic "pencil"—traveling about 2 miles a second, or 7,000 miles an hour, from left to right, and 70,000 miles an hour from right to left. Each part of the screen must fluoresce for a short time after the passage of the electron beam, since the image at any point must persist approximately until the next passage of the beam across this same point. For all practical purposes, however, television is instantaneous.



Courtesy RCA Victor Manufacturing Company, Inc.

A twelve-inch kinescope on which televised images are reproduced is here compared with one of the very small tubes in a television receiver.

Frequency modulation seems to be the answer to the radio engineer's dream. This system of radio achieves two desirable objectives not possible in conventional amplitude modulation systems: namely, the elimination of static and the securing of high fidelity in the reproduction of music. Listeners who are accustomed to ordinary radio are amazed by the naturalness and lifelike qualities of the sounds received by frequency modulation, even under extremely adverse conditions.

In amplitude modulation, the form of the carrier wave depends upon the form of the audible sound waves impressed upon it; the frequency is kept extremely constant. In frequency modulation, the reverse occurs. The amplitude is kept extremely constant, while the audible sound waves are impressed upon the carrier wave in such a way that its frequency increases and decreases over a range of perhaps 200 kilocycles at a rate corresponding to the frequencies in the sound being broadcast. In ordinary broadcasting, the frequency range is only about 20 kilocycles, and this is not adequate to permit all of the frequencies of natural sound to be broadcast. Here is the secret of higher fidelity in the reproduction of music by frequency modulation. Furthermore, static disturbances are such that they naturally modify the amplitude of radio waves and thus are reproduced as noise by amplitude-modulation receivers. Receivers for frequency modulation do not respond to amplitude changes, hence static noises are eliminated.

Exercises for Problem Study and Review

1. What is meant by the statement that what paved the way for the telephone was the discovery that sound waves could change the resistance of an electric circuit?

2. Trace the changes that take place in the interval between the

utterance of speech into a telephone transmitter and its reception as sound at the other end of the line.

3. How do radio waves differ from other members of the electromagnetic spectrum?

4. How are the dots and dashes of radio telegraphy transmitted and received?

5. Explain the Edison effect. How is it used in the vacuum tube? What is the grid? What is its function?

6. How is a vacuum tube connected into the circuit when it is to be used as an amplifier? As an oscillator?

7. Trace the formation of the modulated wave.

8. Trace the changes which occur in a simple receiving set from the antenna to the earphones or loud-speaker.

9. In chain broadcasting, why is it desirable that the equipment connecting radio stations by wire be able to transmit a wide range of frequencies?

10. What is meant by putting the wave frequencies "in step"?

11. How do public-address systems work?

12. Explain how the image is transmitted and received in television. How is the persistence of vision involved?

13. Compare the principles of amplitude modulation and frequency modulation. What are the advantages of the latter?

APPLICATION EXERCISES FOR THOUGHT AND DISCUSSION

1. Hard blowing of the nose, especially with one nostril held shut, may spread infection from the nose and throat into the middle ear. Explain.

2. Tell what you think happens within a piano when the loud pedal of the piano is pushed down. Check your answer by examination of one.

3. How would the soprano, alto, baritone, and bass saxophones compare in size? Explain.

4. A vessel sailing in foggy, northern waters blows its foghorn at intervals to detect the presence of icebergs and to find out how far away the menacing object is. Explain.

5. In New York City the League for Less Noise has demonstrated an experimental automobile-horn attachment that prevents the horn from being sounded when the automobile is stationary or traveling at less than 3 miles an hour. What do you think of the effectiveness of such a measure? Has it any disadvantages?

6. Can tunes be played on all instruments used by the orchestra or band? Explain.

7. During parades when long columns of marchers follow a band,

it may be noticed that the rear rows of the column are slightly out of step with the front rows. How do you account for this?

8. It has been demonstrated that a shrill whistle sounded from a vessel in the vicinity of glaciers that come down to the sea, as in Alaska, causes huge amounts of ice to break loose and crash into the water. How would you explain this?

9. It is difficult for a very large crowd of people to sing in unison. Explain.

10. Explain the rise in pitch of an automobile horn as the vehicle approaches you and the drop in pitch as it recedes from you.

11. How can you raise the pitch of music reproduced by a phonograph? What does this do to the harmony and to the quality? How would you explain these results?

12. If thunder is heard five seconds after the lightning is seen, how far away was the flash? (Temperature: 20° C.)

13. The note E in the diatonic scale has a frequency of 320 v.p.s. What are the frequencies of the first four overtones? What notes would they be?

UNIT WORD LIST

pitch
frequency
compression
rarefaction
transverse wave
longitudinal wave
cochlea
basilar membrane
noise
tones
quality
threshold of hearing
threshold of pain
octave
major triad
major chord
even-tempered scale
international pitch
fundamental
overtone
discord
beats
sympathetic vibration
forced vibration
resonance
manometric flame
phonodeik
oscilloscope
decibel
reverberation
acoustics
seismograph
hydrophones
ultrasonic
dictaphone
photoelectric effect
light valve
sound track
radio frequency
audio frequency
video frequency
oscillate
carrier wave
modulated wave
scanning
iconoscope
kinescope
diatonic scale

INTERESTING THINGS TO DO

1. Compare the noise levels in various parts of your school at different times of the day by any method you may be able to devise.
2. Institute an antinoise campaign aimed at ridding your school of undesirable and excessive noise. Be sure (1) that you have a convincing argument that excessive noise exists; (2) that you can show that it is harmful or undesirable; (3) that you have well-laid plans for enlisting student and faculty cooperation in eliminating noise.
3. Make a comprehensive list of Edison's inventions and rank them according to their effect on society.
4. Visit a radio-broadcasting station, find out how sound effects are produced, and report to the class. Demonstrate where possible.
5. Locate several phonographs representing early stages in the evolution of the modern instrument. Play a recording on each of them; compare the results and account for any differences noted.
6. Obtain telephone receivers, transmitters, and other necessary equipment from the school laboratories and set up an experimental telephone system between parts of the building.
7. Demonstrate to the class the pitch range of some musical instruments.
8. Use the piano or another instrument to compare the ranges of the voices in your class.
9. Inspect a motion-picture theater and report to the class (1) on special features observed in connection with its sound-reproducing equipment; (2) on the relation of the architecture and equipment of the building to its acoustics.
10. Report on the contributions of Edison, Von Helmholtz, Bell, Sabine, Dayton C. Miller, De Forest, and other eminent scientists who worked in the field of sound.
11. Have recordings made of the voices of members of the class and use the results as the basis of a plan for speech improvement within your group.
12. Obtain a Galton whistle and test the ability of members of your group to hear sounds in the high-frequency ranges.
13. Make a collection of soundproofing materials. Explain the science ideas underlying their use.

TOPICS FOR INVESTIGATION AND ORAL OR WRITTEN REPORTS

1. The steps in the transmission of conversation from your town to London, England, by telephone.
2. How Alexander Graham Bell's telephone compares, part for part, with those in use today.
3. Why health authorities advise that any severe earache that lasts

for even a short time should be referred to a physician and why they warn that the greatest danger lies in delay.

4. How Marconi's first transoceanic radio telephone worked.
5. Why the telephone receiver reproduces sound with less fidelity than the radio loud-speaker.
6. How changes in pitch are obtained in the various wind instruments of the band.
7. The function of the stops, the various pedals, and the various manuals of the pipe organ.
8. How exact pitch is obtained in the French horn.
9. How the electric organ operates.
10. Soundproofing of broadcasting studios.
11. What function "A," "B," and "C" batteries perform on radios.
12. Famous whispering galleries.
13. The growth of radio.
14. Why sounds over calm lakes are heard much farther and with greater intensity at night than at other times.

INTERESTING BOOKS TO READ

Harlow, Alvin F., *Old Wires and New Waves: The History of the Telegraph, Telephone, and Wireless.* D. Appleton-Century Company, New York, 1936. An excellent and delightful story of communication. Economic and social implications are discussed, as well as scientific principles.

Jeans, Sir James, *Science and Music.* The Macmillan Company, New York, 1938. A comprehensive discussion of just what the title implies. Very readable.

Jones, Arthur T., *Sound.* D. Van Nostrand, New York, 1937. Although a college text, this book contains so little technical and mathematical material that it is a very useful reference for this unit. It gives a splendid background of speech, music, and acoustics.

Miller, Dayton C., *The Science of Musical Sounds.* The Macmillan Company, New York, 1934. A standard reference on research in sound. Many passages form suitable reading for this unit.

Mills, John, *A Fugue in Cycles and Bels.* D. Van Nostrand Co., New York, 1935. Authoritative and interesting account of what science is doing to music and what it can do for music. Includes chapters on noise and acoustics.

Morgan, Alfred, *Getting Acquainted with Radio.* D. Appleton-Century Company, New York, 1940. This book helps you in doing just what its title states. Principles of radio are explained, and a chapter is devoted to the building of simple receivers.

Thomas, Lowell, *Magic Dials.* Polygraphic Company of America, New York, 1939. The story of radio and television told in an inter-

esting manner. Striking illustrations, many of them in natural colors, enhance the book.

Watson, Herbert M., Welch, Herbert E., and Eby, George, *Understanding Radio.* McGraw-Hill Book Company, New York, 1940. A combined textbook and laboratory manual for beginners. Emphasis on practical construction and operation.

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